William Carl Ruediger

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WITH SPECIAL REFERENCE TO INDIVIDUAL DIFFERENCES AND THEIR CORRELATIONS

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INTRODUCTION:

INTRODUCTION—THE PROBLEM

The object of this study was to determine relatively the size of the field of distinct vision in a number of subjects sufficiently large to reveal characteristic individual differences, and then to correlate these differences with other phenomena of vision and with reading rate. It was the hope to contribute something both to the psycho-physiology of vision and to the psychology of reading.

The major part of the time was consumed in mapping fields of acute vision. Usable data were obtained from eighteen subjects, varying, however, greatly in degree of fulness. Full data consisted in the exploration of four meridians in the visual field, this being done for both eyes when used together, and for each eye separately. The work was done tachistoscopically with the *n* and the *u* of ten point type as the units of vision.

In addition to the size and shape of the field of acute vision, there was also obtained from some or all of the subjects the extent of the color zones, visual acuity, both for near and for far vision, retinal sensitivity or inertia, rate of perception as determined by the A test, attention span as determined by the number of short vertical lines simultaneously seen, controlled association time, normal silent reading rate, and the number of reading pauses per line.

These various items were not only correlated with the extent of acute vision but also among themselves. Especially were there many correlations made with reading rate. It was the aim to determine, if possible, to what extent reading rate is determined by the mechanism of vision and to what extent by the rapidity of the central processes.

It is important to make such analyses, probably more for the sake of pedagogy than for psychology; but before psychological facts and principles can be applied in teaching they must themselves be understood. Before we can teach reading with scientific intelligence we must ascertain all the essential elements and conditions of the reading process, and especially must we ascertain to what extent these are under the teacher's control. To what extent, for example, is reading rate dependent upon comparatively unalterable natural gifts, and to what extent upon variable methods of instruction?

As yet this question and others of a similar nature cannot be fully answered, but we are beginning to see where the problems lie. After these are ascertained we must transfer our investigations from adults to children. So far, experiments have been almost entirely conducted with adults whose reading habits were already well estab-

lished. This has been necessary in order to obtain an analysis of the reading process in its finished form. But once having ascertained its different factors, the next logical step is to attack the genesis of the process. It is here that we should learn most for pedagogical control, but we would no doubt also gain psychological information not obtained from adults.

The ocular condition of the subjects that took part in this investigation is to a certain extent indicated in some of the tables that follow, especially Tables XI and XIII, but as this was an investigation primarily in vision, a few additional facts may be noted. Subjects J. M., G. B., S. F. and W. B. had no known defects; G. S., H. W. and H. C. were slightly hypermetropic; E. W., W. R., F. H., J. S., F. B., L. W and E. D. wore glasses for astigmatism, but only in the last three was the defect at all marked. The data from E. D. were discarded, with the exception of the reading test. H. R., F. C. and P. L. wore glasses for myopia, and A. A. was slightly myopic and in the left eye astigmatic. She also wore glasses. The defects, where present, with the exception of the hypermetropic cases, had been corrected by glasses, which the subjects were permitted to wear during the experiments.

This research was conducted in the psychological laboratory of Columbia University between March, 1906, and May, 1907. My acknowledgments are due to Professor J. McKeen Cattell, in whose class on "individual differences" the problem arose, and under whose personal guidance the research was conducted; to Professors R. S. Woodworth and E. L. Thorndike for valuable suggestions and criticisms; to Dr. W. A. Holden for making the ophthalmoscopic examinations; to L. P. Siceloff for mathematical assistance; and to the persons who gave me so generously of their valuable time in acting as subjects. Their number alone forbids their separate mention. I cannot forbear acknowledging the constant assistance of my wife, Hazel Pietsch Ruediger, which made this early publication of the study possible.

PART I—HISTORICAL

Researches in the field of indirect vision may be roughly divided into three classes,—those pertaining to the sensitivity of the peripheral retina to color, those pertaining to its sensitivity to light, and those pertaining to its sensitivity to forms, or its acuity for distinguishing objects. Varying numbers of studies have been made in each of these fields. The color sense has been most assiduously explored, the most painstaking and also the most recent extensive study being that of John Wallace Baird.[1] Less has been done in the other two fields but they too have not been neglected. Mention need be made at this point only of the work of Kirschmann,[2] Wertheim,[3] and Wirth.[4]

The first published account of an attempt to explore the retina with a view to determine the form and extent of its sensitive surface we owe to Dr. Thomas Young.[5] In a lecture before the Royal Society of London, in 1800, he said:

> The visual axis being fixed in any direction, I can at the same time see a luminous object placed laterally at a considerable distance from it; but in various directions the angle is very different. Upwards it extends to 50 degrees, inwards to 60, downwards to 70, and outwards to 90 degrees. These internal limits of the field of view nearly correspond with the external limit formed by the different parts of the face, when the eye is directed forwards and slightly downwards, which is its most natural position . . . . The whole extent of perfect vision is little more than 10 degrees; or more strictly speaking, the imperfection begins within a degree or two of the visual axis, and at the distance of 5 or 6 degrees becomes nearly stationary, until, at a still greater distance, vision is wholly extinguished. The imperfection is partly owing to the unavoidable aberration of oblique rays, but principally to the insensibility of the retina . . . . The motion of the eye has a range of about 55 degrees in every direciton, so that the field of perfect vision, in succession, is by this motion extended to 110 degrees (pp. 44-46).

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[1] *The Color Sensitivity of the Peripheral Retina*, Washington, 1905. The reader is referred to this study for a summary of the literature in this field and for a bibliography.

[2] August Kirschmann, 'Ueber die Helligkeitsempfindung im indirectem Sehen,' *Phil. Stud.*, V, pp. 447-497.

[3] Th. Wertheim, 'Ueber die indirecte Sehscharfe,' *Ztsch. f. Psych. u. Physiol.*, pp. 172-187.

[4] Wm. Wirth, 'Die Klarheitsgrade der Regionen des Sehfelds bei verschiedenen Verteilungen der Aufmerksamkeit,' *Phil. Studien*, June, 1906.

[5] *Philosophical Transactions*, V, 91, 1801, p. 23ff.

Young does not indicate in detail how he obtained these results, but he experimented roughly with objects and 'luminous points.'

Purkinje[1] studied the acuity of indirect vision by placing knitting needles into a graduated paste-board arc, in whose center the eye was situated, and observing the distinctness with which they appeared when he fixated one of them.

The first actual measurements of retinal acuity are given by Hueck.[2] He made a comparative study of the acuity of direct and indirect vision. The latter he investigated by means of black dots, lines, and squares of various dimensions on a white background, determining how far from the fixation point and with what size retinal image they could still be distinguished or recognized. He gives his results in a number of tables, the essentials of one of which are here reproduced. He found that lines fused according to the following data:

Visual angle of the retinal image	Deviation from the fixation point
1′ 30″	$1/2°$
2′ 33″	2°
2′ 59″	6°
5′ 46″	8°
13′ 45″	11°
14′ 55″	14°
21′ 55″	20°

Volkmann introduced the method of momentary illumination with the electric spark, in order to eliminate the disturbing influence of eye movements.[3] He endeavored to determine the sensitivity of the peripheral retina in several ways. First he determined at what distance from the eye, at various angles from the center, round black dots on white paper could still be recognized. He calculated the retinal images and compared them with the smallest image that could be perceived at the center. He repeated the experiment with an upright thread of a spider web and obtained angles only one-tenth as large as those from the dots. The only conclusion

[1] Johannes Evangelista Purkinje, *Beitrage zur Physiologie der Sinne*, 1825. For the data from Purkinje I am indebted to Aubert, *Physiologie der Netzhaut*, Breslau, 1865, pp. 336–337. The original sources were not accessible to me at the time of writing.

[2] Mueller's *Archiv.*, 1840, pp. 81–97.

[3] *Handwörterbuch der Physiologie* (Wagner's), III, 1, 1846, p. 332f.

he draws at this point is that the acuity decreases rapidly from the center.

Volkmann next ascertained the smallest retinal image with which two parallel lines could be distinguished on various parts of the retina. The experiment duplicated the work of Hueck, but he obtained visual angles about ten times as large as those of Hueck. Volkmann noticed this discrepancy but made no attempt to explain it. The results of later investigators show Hueck to have done the more careful work.

Aubert and Foerster set themselves a problem in some respects similar to mine.[1] They determined both the extent and the shape of the field of vision within which certain units could be recognized. Their experiment they varied in a number of ways and they obtained some significant results.

In the first experiment to be noted they eliminated the influence of eye movements by illuminating the objects to be recognized with an electric spark. As such objects they used numbers and letters printed on paper charts 2 feet wide and 5 feet long. These charts they mounted on horizontal rollers so that the field could be changed between every two exposures. This prevented the subjected from becoming familiar with any part of it. They used four charts with characters of different sizes and at various distances apart; and they employed ten distances varying from .1 to 1 meter between the subject and the chart. They found that "the larger the angle made by the line of direction of an object with the line of sight, the larger must the visual angle of the object be in order to be recognized," (p. 239); and that "with a constant visual angle of the characters, small near characters can be recognized on a larger area of the retina than large distinct characters" (p. 240).

The latter peculiarity attracted Aubert's attention and he investigated it further, this time with constant illumination. Various distances from the fixation point were again used, a definite point was fixated, and the objects to be recognized were shifted in and out in various planes. The apparatus, by means of which definite positions of the head and objects were secured, need not here be described.[2] As objects, two black squares upon white paper were used. Their distances apart were the same as their lengths of side, which were 20 mm., 8 mm., and 4 mm. These dimensions gave the same visual angle, 1° 8′, at the distances of 1000, 400, and 200 mm. respectively.

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[1] *Physiologie der Netzhaut*, pp. 237–253.

[2] For a description and cut the reader is referred to p. 241, *Op. Cit.*

In the horizontal meridian the average of four observations gave the following angular extents of the visual fields:

For 20 mm.	squares,	distant	1000 mm.,	39°
" 8 mm.	"	"	400 mm.,	54°
" 4 mm.	"	"	200 mm.,	67°

When the visual angle was changed to 34′ the results were:

For 8 mm.	squares,	distant	800 mm.,	35°
" 4 mm.	"	"	400 mm.,	43°

More tables are given by Aubert, but it is sufficient to say that the data agreed closely with those obtained by the method of momentary illumination. With the same visual angle, small near objects may be recognized in a larger extent of the retina than large far objects; and for the same object a fairly constant ratio exists between the size of the visual angle of the object and its deviation from the fixation point. On the other hand, when the distance of the object is kept constant, the deviation at which the object may be recognized increases more slowly than the visual angle of the object.

To explain this puzzling phenomenon, as he calls it, Aubert assumed that in accommodation for distinct vision occurred a distortion of the rod and cone layer which disturbed the passage of the rays of light. The assumption that accommodation for the peripheral regions of the retina is less perfect in distant than in near vision he rejects. The shifting of the node, owing to changes in accommodation, does not explain the phenomenon either, for that should give just the opposite result.

In the experiment with momentary illumination both Foerster and Aubert noticed that more characters could be seen in the horizontal than in the vertical direction. This led them to a more careful exploration of the various meridians in order to ascertain how the sensitivity of the retina decreased. They did this again with constant illumination. They used a flat surface, the center of which was fixated, and they proceeded much as is frequently done in mapping the color zones. They recognized that they might have used an arc, but as they explored only a small field near the fixation point, they regarded this unnecessary. As objects, they used this time round black dots, 2.5 mm. in diameter and 14.5 mm. apart. Both Foerster's and Aubert's eyes were tested, and eight meridians were explored in each eye. Irregular horizontal oblongs were obtained which differed both between the subjects and for the separate eyes, showing that the capacity of the retina to perceive distinctly two points decreases very unequally in the various meridians, and it is different for each eye.

From the time Aubert and Foerster published their work, nothing appeared in the literature on the acuity of indirect vision till 1873. In that year Dor published a study on *Beiträge zur Electrotherapie der Augenheilkunde*,[1] in which he gave determinations of the acuity from the center out as far as 40 degrees. During the following ten or twelve years a large number of studies appeared, but since 1884 little activity has been manifest in this particular field.

All the investigators during this period aimed to determine the acuity of peripheral parts of the retina relative to the center. They all used the perimeter method, with constant illumination, and they varied little from the lines laid out by Hueck, Volkmann, and Aubert and Foerster. As units of vision Dor,[1] Dobrowolsky and Gaine,[2] and Hirschberg[3] used Snellen test types; Matthiessen[4] used six letters from Monoyer's table; Schadow[5] used the letter E; Königshöfer[6] used black dots; and Landolt,[7] Butz,[8] and Charpentier[9] used black squares of different sizes.

The results obtained vary no more than one would expect from the different procedures followed and from the individual differences of the subjects. Within 15 degrees of the center all the investigators found little difference between the inner and the outer radii, and between the upper and the lower. Beyond 15 degrees the fields were usually found to be largest on the lateral side, with the inner, lower, and upper sides coming in the order mentioned. Landolt found the lower field to be the largest, with the lateral next; Königshöfer found

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[1] H. Dor: *Archiv f. Ophth.*, 1873, 3, p. 321f.

[2] Dobrowolsky and Gaine, 'Über die Sehschärfe (Formsinn) an der Peripherie der Netzhaut,' *Archiv. f. d. Gesamte Physiologie*, Bd. XII, 1876.

[3] Hirschberg, 'Über graphische Darstellung der Netzhautfunction,' *Archiv. f. Anat. u. Physiol.*, 1878.

[4] Ludwig Matthiessen, 'Ueber die radiare Ausdehnung des Sehfeldes und die Allometropie des Auges bei indirectem Sehen,' *Arch. f. Ophth.*, XXX, 1884.

[5] Schadow, 'Die Lichtsempfindlichkeit der peripheren Netzhautteile im Verhalniss zu deren Raum und Farbensinn,' *Archiv. f. d. ges. Physiol.*, XIX, 1879, p. 4[illegible]f.

[6] Oskar Königshöfer, *Das Distinctionsvermögen der peripheren Teile der Netzhaut*, Inaug. Dissert., Erlangen, 1876. (Data obtained from Charpentier's review.)

[7] Landolt, *Handbuch der gesamten Augenheilkunde*, Graefe und Laemisch, 1874, III. (Data obtained from Charpentier's review.)

[8] R. Butz, 'Untersuchungen uber die physiologische Function der Peripherie der Netzhaut,' *Arch. f. Anat. u. Physiol.*, 1881, p. 437f.

[9] A. Charpentier, 'De la vision avec les diverses parties de la retine,' *Archiv. de Physiol., norm. et pathol.*, IV, 1877, pp. 894–945.

the inner field the largest; and Schadow found the lower field following the lateral in size. These variations may be owing both to the differences in the methods employed and to the differences in the eyes tested.

The effect of practise received special attention by Dobrowolsky and Gaine. Its influence was found to be great. A unit that was just recognized 30 degrees from the center on the first trial was recognized 45 degrees from the center on the fifteenth trial, and 60–65 degrees from it after three and one-half months of practise. Schadow attributed some of the individual differences he found to the differences in amount of practise.

The amount of work done by these investigators in the studies mentioned varied greatly. The acuity of indirect vision frequently comprised but a part of their problem, a large share of their time also being given to ascertaining the sensitivity of the peripheral retina to light and to color. Butz apparently tested but one eye, the left eye of his assistant; Charpentier explored two inner fields; Dor, Landolt, and Matthiesen each used two subjects and explored four radii in each eye; Hirschberg explored eight radii in both eyes of three subjects; and Dobrowolsky and Gaine worked on the effect of practise with twelve eyes. Schadow aimed to allow for individual variations and so explored four radii in the eyes of nine subjects. He thought that the discrepancies between the work of other investigators might be owing to individual differences, and this point was well substantiated. He found that the diameters connecting points of corresponding acuity in the eyes of his subjects varied as 2–1, and that women had larger fields than men. Owing to the small number of subjects, the conclusion in regard to sex differences is not safe. My data revealed no such differences.

The reason why the acuity decreases as we pass from the center to the periphery of the retina has been considered and investigated by a number of men. Aubert tested the matter in several ways and concluded that the difference was owing, in the main, to the anatomical structure of the retina. This is the conclusion reached also by Dobrowolsky and Gaine, and by Wertheim.[1] In addition to the structure, Dobrowolsky and Gaine attributed some of the differences in acuity to practise, but practically none to the greater faintness of the image and to the aberration of light. Wertheim made an attempt to correct for imperfect refraction on the peripheral retina by means of lenses, but without effect. Every test and consideration points to

[1] Th. Wertheim, 'Uber die indirecte Sehschärfe,' *Zeitsch. f. Psych. u. Physiol.*, Vol. VII, pp. 172–187.

the conclusion that by far the largest factor in causing the decline in acuity must be looked for in the structure of the retina.

Pietsch and Wertheim worked a decade later than the group of men just mentioned. Wertheim determined the relation between the acuity of direct and indirect vision in his own eyes. As units he used five small wire gratings, circular in form, with dimensions of such size as to give equal visual angles at the distances employed. The gratings simultaneously with the fixation point were moved toward and away from the eye, and the point at which the bars were just visible was determined. The results are given in a table, and graphically in two figures. Within fifteen degrees of the center he found little difference between the inner and the outer, and between the upper and the lower radii. But beyond fifteen degrees he found that "the acuity of vision decreases most rapidly above; a little less rapidly below; still more slowly on the medial side; and most slowly on the lateral side. For example, if one represents the central visual acuity by 1, the acuity thirty degrees from the fixation point becomes: lateral 0.072, medial 0.056, below 0.044, above 0.039. At forty degrees these become: lateral 0.051, medial 0.04, below 0.032, and above 0.023" (p. 184 *L. c.*).

Pietsch determined the influence of various conditions of refraction on the extent of the visual field.[1] He used a Foerster perimeter and explored the fields of seven emmetropic, twelve myopic and eleven hypermetropic eyes with white, blue and red papers 5 mm. square, and he concluded that for hypermetropic eyes the fields are a trifle larger than for emmetropic eyes, namely 2 degrees for white, 3 degrees for blue and from 1–2 degrees for red. For myopic eyes the fields are smaller, —2 degrees for white, 6–7 degrees for blue and 4 degrees for red.

The tachistoscopic study of reading has yielded some data that should be noted here. Cattell, with whose researches the tachistoscopic study of the reading process began, investigated also the extent of the simultaneous grasp of consciousness. He exposed in the fall-chronometer for a time of ten sigma short vertical lines, numbers, letters, words, and sentences, and found that consciousness could simultaneously grasp from 3–6 lines, approximately the same number of letters and numbers, two or three, and occasionally four words of one syllable, and sentences composed of from three to seven

[1] H. Pietsch, *Die Ausdehnung des Gesichtsfeldes für weisse und farbige Objekte bei verschiedenen Refraktionszuständen*, Dissertation, Breslau, 1896. (Data obtained from review in *Zeitsch. f. Psychol.*, XIV, p. 477.)

words.[1] In sentences about three times as many letters were seen as when they were unconnected, and when words formed sentences about twice as many were read as when they were unconnected. This was taken to mean that words and even sentences were read as wholes.

Erdmann and Dodge duplicated these experiments of Cattell and obtained closely corresponding results. They found that infallibly four, and generally five letters could be recognized and alphabetically reproduced when exposed for 100 sigma.[2] Four or five times as many were read under similar conditions when they formed words.

These investigators also exposed a page of Helmholtz's *Physiologische Optik* and determined roughly how much of the text could be seen simultaneously.[3] Letters were recognized about 20 mm. from the fixation point, both to the right and to the left, and 10 mm. from it up and down.

Huey found in exposing sentences without context that four subjects recognized on the average words or parts of words over a horizontal extent of 24.49 mm.[4] The individual variations were large, extending from 11.25 mm. to 34.88 mm. The largest amounts seen varied from 40 to 50 mm., with an average of 46 mm. The average amounts read to the right and to the left of the fixation point were nearly equal, but those for particular exposures were frequently very different. Whenever much was seen to one side of the fixation point, the chances were that little was seen on the other side.

Hamilton obtained results closely similar to those of Huey.[5] In one table that he gives it is shown that five subjects read on the average an extent of 37.3 mm. when the words formed sentences, 27.6 mm. when the words formed phrases, and 15.8 mm. when the words were unconnected. The average amounts read to the right and to the left of the fixation point were again nearly equal. One subject, however, read uniformly more to the left than to the right. The largest amount read per fixation by Dearborn's subjects when reading from a newspaper was 28.2 mm., but ordinarily the amount fell short of this.[6]

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[1] J. McKeen Cattell, 'Ueber die Traegheit der Netzhaut und des Sehcentrums,' *Philosophische Studien*, Vol. III, pp. 121–127. *Brain*, V, VIII.

[2] *Psychologische Untersuchungen über das Lesen auf Experimenteller Grundlage*, Halle, 1898, Chapter 5.

[3] *Op. cit.*, pp. 39–41.

[4] E. B. Huey, *American Journal of Psychology*, Vol. XI, p. 300.

[5] F. M. Hamilton, an unpublished study.

[6] W. F. Dearborn, *The Psychology of Reading*, this series, Vol I, No. 4, p. 23.

These experiments cannot be taken to measure the retinal extent of clear vision, or to indicate individual differences in this respect, and are not so taken by the investigators. What they do measure are certain forms of mental grasp, which, as will be shown later, do not correlate in any significant way with the size of the field of distinct vision. The amount read per fixation, for example, does not depend on the amount that can be seen, but on the amount that can be assimilated.

PART II—METHODS AND RESULTS

As has already been mentioned in the introduction, I set myself the task of ascertaining in a number of persons the fields of acute vision relative to a given visual unit. It was the aim to map a sufficiently large number to bring out characteristic individual differences, which could then be correlated with reading rate, the color zones, visual acuity, retinal inertia, and other phenomena of vision.

The difference in the size of the fields in different persons would be indicated by the varying distances from the fixation point at which they could recognize similar objects. The determinations could be made in one of several ways. Heretofore they have usually been made in work of this nature by the method that may be called the perimeter method. In this method the subject maintains steady fixation while the visual unit is moved toward or away from the fixation point at a definite distance from the eye. With a practised subject and in work requiring the unit to be brought no nearer than about 10 degrees this may be satisfactory, but with unpractised subjects and in explorations within 10 degrees of the fixation point, it is not satisfactory. An unpractised subject cannot maintain sufficiently steady fixation, and it is questionable that a practised one can in the conditions indicated. The eye reacts reflexly to peripheral stimuli so that a desire to maintain steady fixation is of little avail. It is the instinctive tendency of the eye to bring everything that appears in the peripheral field to the point of clearest vision.

The influence of eye movements may be eliminated either by momentary illumination, or tachistoscopically by short time exposure. In this experiment it was eliminated by means of the tachistoscopic method. The time of exposure must be less than the reaction time of the eye. This Dodge[1] has shown to be rather more than 160 sigma.[2] So as to be well within the limit, an exposure time of 50 sigma was used. For distances within 10 degrees of the fixation point this gave better results than longer times; in fact, for a few subjects, 35 sigma gave sightly better results than 50. A longer exposure time tended to make the exposed letter appear entirely black, so that recognition was difficult or impossible.

Fifty sigma, however, was not the total time of the impression on the retina. The background being a dull black, reflecting about 6 per cent of the light, the after-image materially prolonged the retinal impression. This, of course, in no way interfered with the experi-

[1] *Psychological Review*, Vol 6, p. 481.

[2] 1 sigma = .001 sec.

ment. Eye movements being excluded, I wanted the impression to be as clear as I could well get it.

As exposure apparatus, the Cattell fall-chronometer was used for the horizontal meridian, and a pendulum screen for the vertical and the oblique meridians. Both of these instruments expose the object in the light for which the eye is adapted. My experiments were uniformly made by daylight.

The fall-chronometer was not suitable for the vertical and the oblique meridians for two reasons. In the first place, the object above the fixation point would always be exposed sooner than the one below, and, secondly, the exposure time would be shorter for the lower object than for the upper, owing to the increase in the speed of the falling screen. These two factors might prove decidedly disturbing and were eliminated by the use of the pendulum screen. This particular apparatus was also devised by Professor Cattell, for another purpose, and worked as smoothly and satisfactorily as the fall-chronometer.

The method of operation of the two instruments used is so well known that it need not be described. The exposure time of the pendulum was ascertained with the Hipp chronoscope, and that of the fall screen both with the chronoscope and by means of the formula for falling bodies. The discrepancy between the two determinations was small, showing that friction retarded the screen but little.

The point of fixation, directly in front of the center about which the letters to be recognized were distributed, was composed of a small bead of dried glue, attached to a taut, horizontal human hair in each apparatus. This hair was securely fastened to the apparatus so that it would not shake or move out of place during the progress of the experiment.

The distance between the fixation bead and the card was in each instrument about three millimeters. This disturbed the clearness of the image very little, if at all, for letters exposed at the fixation point were not missed. With most, if not with all of the subjects, moreover, even the slight disturbance that was possible was overcome by accommodating for the card instead of the bead. In my own case I was well aware of this. I could accommodate at will for either the bead or the card, and in the course of the experiment accommodated uniformly for the card.

Owing to the nature of the apparatus used, the letters were exposed in a plane instead of a surface corresponding to the horopter. But as they were never exposed more than 7.6 degrees from the fixation point, those farthest out were scarcely two millimeters farther

from the eye than the point fixated. This was not enough to cause any appreciable amount of disturbance, especially in indirect vision when accommodation is not exact anyway.

The screen in each apparatus was held up by an electro-magnet, of which the subject himself controlled the switch. This enabled him to release it just when he had his eyes properly focused. As an attention signal the word "now" or "ready" was given after the card to be exposed had been put in place.

The making of the exposure cards presented a number of problems. First of all came the selection of units to be recognized or distinguished. Upon their size and characteristics the resulting field obviously depends. Just as the extent of the color zones, so the extent of acute vision is a relative affair. They both depend upon the nature of the stimulus employed. Aubert and Foerster, it will be remembered, found that the extent on the retina on which an object could be recognized depended both upon the size and the character of the object used, and upon its distance from the eye. I found, for example, that at the same distance from the eye, a capital M and a capital W three millimeters high could be distinguished at about twice as big an angle from the line of sight as an *n* and a *u* one and one-half millimeters high.

What we should have is a standard set of units for experiments in vision. Ordinary printed letters and numbers do not answer the purpose because they are not visible with equal ease, and especially because type from different fonts is too variable. The *n* and the *u*, for example, printed from one font of ten point type, need not be comparable in distinguishability with the same letters printed from another font of ten point type.

Perhaps the most desirable units would be small natural objects closely similar in form that could be obtained the world over. But them we may at once dismiss from the discussion, because, as far as I am aware, none are available. The alternative is to look for units in the printer's art. They might perhaps be drawn to accurately described dimensions, but that would not be entirely satisfactory. Only an expert draftsman could make them, and then one could not be sure that any two draftsmen would follow the directions in precisely the same way.

From the printer's art any number of suitable units could be obtained. Dots, lines and various kinds of geometrical forms of standard dimensions suggest themselves. A good unit would be a hook, composed essentially of a square with one side open. Being as wide as tall, it could be faced in four different directions and there would

be nothing but the open side as a clue to its position. These hooks would thus furnish six different pairs of units to distinguish. A standard set should include a dozen or more different sizes varying in dimensions from a certain small fraction of a millimeter to eight or ten millimeters. This would furnish a choice for many different kinds of work.

Practically the same desideratum would be met by capital E's, such as are now used in testing visual acuity. These should also be as wide as they are tall. Another possible unit would be a circle with, say, one-eighth of the circumference left open.[1] This would have the advantage of furnishing a still larger number of units than either the hook or the E. In some work this might save a great amount of time in making the determinations.

No standard set of units being available, I resorted to printed letters. In selecting these, clear, evenly printed ten point type, which was available in a supply of reprints, was chosen. The letters answered the demands of the experiment very well. They were large enough to be recognized about four degrees from the fixation point at 30 cm. from the eye, thus yielding a field of sufficient and convenient size; and they were small enough to be, in the main, unrecognizable eight degrees from the fixation point, the extent of the field available in the fall-chronometer, in the size this instrument is usually constructed.

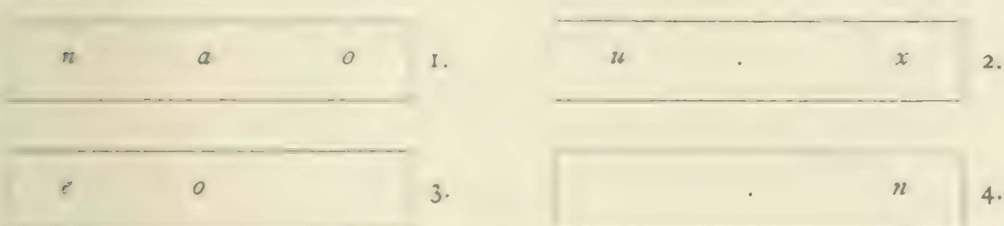

Fig. I.

After having settled upon the style of letters to use, the problem of placing them on cards presented itself. Here there were four possibilities, illustrated by Figure I. One letter could be placed at the fixation point, and two others equidistant from it (No. 1); two could be placed equidistant from the fixation point with none at the center, (No. 2); one could be placed at the center and one in the margin, in either direction from the fixation point (No. 3); or, finally, one could be placed in the margin with none at the fixation point (No. 4).

All of these possibilities were tried out in the preliminary experiments. No. 1 proved clearly too complex for the purpose of the

[1] Suggested by Professor Cattell

study. Three letters can be recognized and named on short exposure when printed close together and looked at directly, but even then they approach the limit of the attention span in some people. But this task for the attention becomes too great when two of the letters are seen indirectly. The subjects frequently said that they had recognized all three of the letters, but after naming one, could not remember the others.

The same objection holds in a less degree against No. 2 and against No. 3. Had the experiment been one in attention span, this would not have been an objection; but for my purpose it completely vitiated the results I was after. It was not my aim to measure any qualities of attention or mental grasp, but to ascertain the sensitivity of the retina for small differences in form as one passes from the fovea to the periphery, the tax upon the attention being at the minimum. Clearly this requirement would be best satisfied by the conditions of No. 4, provided that fixation could be maintained by the subject. This proved to be a smaller difficulty than one might suppose. It was readily overcome by letting the letter be just as likely to appear on one side as on the other, no matter which meridian was being explored. As there were never less than eight, and usually from twelve to twenty-four cards in a series, which were frequently shuffled, the subjects had no chance to keep track of individual cards, and none attempted it. At first, three of the subjects tried a few times to anticipate the side on which the letter might appear, but the disappointment on having it then appear on the other side was too great and they soon gave it up. They learned, too, that one could make the best record by maintaining steady fixation at the point indicated for the purpose.

The simple arrangement of No. 4, which proved to be entirely satisfactory, was therefore adopted. It gave the attention never more than one simple thing to do, thus letting the results depend almost entirely on the acuity of the retina. Besides taxing the attention of the minimum, this arrangement was also well suited to bring out any differences that might exist in the acuity of the opposite sides of the retina. Had the letters appeared on the opposite sides simultaneously this would have been much more likely to cause complications.

In the preliminary experiments most of the letters of the alphabet were used. It was some time before it occurred to me to use just two, and have them distinguished. The two letters selected were "n" and "u", which are herewith reproduced in the quotation

marks.[1] These letters are very much alike in form, and to distinguish them one must see them with some distinctness. A vague outline impression is not sufficient. One of the chief gains in using two letters came in working up the results. It allowed the method of 'right and wrong cases' to be applied in large part.

The letters were pasted upon pieces of white cardboard. The distances from the fixation point generally used were 10, 15, 20, 25, 30, 35, and 40 mm., or 1.91, 2.86, 3.81, 4.76, 5.71, 6.65 and 7.60 degrees. These answered the purpose very well except for one subject, J. R. S., who had an abnormally small field. For him the distances 5, 7.5 and 10 mm. exhausted the range from distinct to entirely indistinct vision. The letters were mounted so that the center was the required distance from the fixation point. Any other arrangement, it seemed, would introduce slight inequalities. Care was taken to select only perfect letters, printed with clear black lines, uniform from letter to letter. The cards were examined frequently and whenever a letter had become perceptibly worn it was replaced. The cards, too, had to be changed often, owing to their becoming soiled.

So as to avoid complications coming from the direction of attention, it was the aim to expose the cards of all the distances used with one subject in one series. This was done in the main, but it occasionally happened that farther or nearer distances had to be explored after the experiment had been in progress for some time. The results so obtained were carefully compared with those obtained when the cards were all in one series. It was thought that the subject, knowing the distances at which the letters would appear, might direct his attention accordingly. No effect coming from the influence of this was noticeable, however. This is really what should have been expected, because the letters being as likely to appear on one side as on the other, the subject could not direct his attention to any particular point. But even after this was evident I continued in my aim to explore all the distances together, so as to get the data for all under similar conditions.

The apparatus was so placed that the fixation point was about 29.3 cm. from the cornea, or 30 cm. from the crossing point of the lines of direction in the eye, which is about 7.2 mm. back of the cornea.[2] The constancy of the distance was maintained by means of a guard resting on the root of the nose. This distance was very close to the average reading distance and was adhered to for all the subjects,

[1] For the type from which the letters are reprinted I am indebted to Mrs. F. C. Erem of Dillon, Montana, owner of the *Dillon Examiner*.

[2] Sanford, *Experimental Psychology*, p. 106.

save one. This subject, G. S., was far-sighted, and, after having obtained some data from him at 30 cm., the distance was changed to 40 cm. This enabled him to accommodate with greater ease and his results showed greater regularity, especially with the letters nearer the fixation point. Only the results obtained at the farther distance were retained, but this would scarcely have been necessary because the averages in the two sets of data differed little from each other. This being true, no attempt was made to adjust the results for distance in order to make them comparable with those obtained from the other subjects. They appear to be comparable as they stand. What was gained by bringing the image of the letter nearer to the center of the fovea seems to have been lost by decreasing the size of that image. The extent upon the retina on which an object can be recognized depends directly upon the size of the object, and inversely upon its distance from the eye.

In this part of the research, data were obtained from eighteen subjects, but not the same amount from each. That from eleven only was regarded sufficient to be tabulated in detail (Tables I to VII). From the remaining seven, however, enough were obtained to be used in the correlations. The deviation at which the letters could be distinguished seventy-five per cent of the time was determined with a fair degree of assurance in all, and the ninety per cent deviation in three (see Table VIII).

The chief reason why more could not be obtained from these, and why full data could not be obtained from each subject, was the limitation in the amount of time that could be given to the work, especially by the subject. To get full data from one subject required approximately thirty hours. This is clearly too much time to give to one subject in a study purporting to ascertain individual differences, and indicates that the method adopted is not feasible for this kind of work. Something more rapid is needed when individual differences are looked for, so that more ground may be covered. This might be achieved by using as a unit the circle with one-eighth of the circumference left open. This would allow but one chance in eight to guess its position, whereas the *n* and the *u* allowed one chance in two. Results could therefore be obtained more rapidly.

Full data from a subject consisted in the exploration of four meridians,—the horizontal, the vertical, and two oblique meridians midway between these, *i. e.*, at forty-five degrees, this to be done for both eyes together, and for each eye separately. All these meridians were explored in only four subjects. In three others the horizontal and the vertical meridians were explored in both eyes and in each

TABLE I.—SUBJECT S. F.

Distance in mm.	Distance in degrees.	No. judgments.	Horizontal. Right side. Av.	M.V.	P.E.	Horizontal. Left side. Av.	M.V.	P.E.	No. judgments.	Vertical. Up. Av.	M.V.	P.E.	Vertical. Down. Av.	M.V.	P.E.	No. judgments.	Oblique—Up. Right side. Av.	M.V.	P.E.	Oblique—Up. Left side. Av.	M.V.	P.E.	No. judgments.	Oblique—Down. Right side. Av.	M.V.	P.E.	Oblique—Down. Left side. Av.	M.V.	P.E.
Both eyes.																													
10	1.91								80	96	4.8	1.4	95	5	1.5														
15	2.86								100	89	5.4	1.4	93	7	1.8														
20	3.81	70	96	5	1.6	99	2	.7	100	68	6.8	1.7	77	7.6	1.9	60	95	5	1.7	95	5	1.7	60	90	3.3	1.2	93	4.3	1.4
25	4.76	110	95	5.7	1.4	92	7.3	1.9	100	60	8	2	69	5.6	1.5	60	82	2.7	.6	83	4.3	1.4	60	83	4.3	1.4	87	4.3	1.4
30	5.71	110	88	9.6	2.5	93	5	1.3	90	50	8	2	61	3.5	.9	60	65	5	1.7	85	6.6	2.3	60	73	4.3	1.4	83	4.3	1.4
35	6.65	110	66	6.7	1.7	70	9	2.2								60	67	6.6	2.3	70	3.3	1.2	60	68	8.3	2.9	60	6.4	2.3
40	7.60	110	67	7	1.8	62	7.3	1.9																					
Right eye.																													
10	1.91								40	98	3.7	1.5	95	5	2.1														
15	2.86								90	86	4.9	1.4	90	6.6	1.8	20	100			100			30	97	4.6		93		
20	3.81	70	96	4.8	1.5	91	4.7	1.5	100	77	7	1.8	75	7	1.8	100	85	7.5	2.2	90	5	1.5	80	78	8	2.4	80	9	2.7
25	4.76	70	80	8.6	2.7	83	8.6	2.7	100	62	6.4	1.7	57	7.6	1.9	100	76	6.2	1.8	73	5.6	1.6	80	70	5	1.5	80	5	1.5
30	5.71	70	74	6.5	2	71	7.3	2.3								100	75	6.2	1.8	78	5.6	1.6	80	56	6.2	1.8	73	5.4	1.6
35	6.65	70	67	7	2.2	57	9	2.8																					
40	7.60	30	56	4.6		53	4.7																						
Left eye.																													
10	1.91								40	100			98	5	2.1														
15	2.86	70	96	5	1.6	97	4	1.3	100	90	6	1.6	91	5.4	1.4	30	97	4.3		94	8.8		30	100			97	2.3	
20	3.81	100	85	5	1.4	92	6.4	1.7	100	83	6.2	1.6	74	6.8	1.8	80	83	6.2	1.8	86	6.2	1.8	80	76	6.2	1.8	90	7.8	2.3
25	4.76	70	80	8.6	2.7	79	8.6	2.7	100	61	7.4	2	67	9	2.4	80	71	4.2	1.3	80	5	1.5	80	75	7.8	2.3	80	5	1.5
30	5.71	70	73	4	1.3	82	2.5	.8								80	65	6.2	1.8	74	4.7	1.4	80	60	4.4	1.3	66	6.2	1.8
35	6.65	70	57	6	1.9	59	7.8	2.5																					
40	7.60	30	56	8.6		50	6.6																						

Table V.

Subject W. B.

Distance in mm.	Distance in degrees.	No. judgments.	Horizontal. Right side. Av.	Horizontal. Right side. M.V.	Horizontal. Right side. P.E.	Horizontal. Left side. Av.	Horizontal. Left side. M.V.	Horizontal. Left side. P.E.	No. judgments.	Vertical. Up. Av.	Vertical. Up. M.V.	Vertical. Up. P.E.	Vertical. Down. Av.	Vertical. Down. M.V.	Vertical. Down. P.E.
Both eyes.															
10	1.91								20	95			95		
15	2.86								60	92	3	1	95	5	1.7
20	3.81	100	91	4	1	91	4	1	100	87	7	1.8	77	5.6	1.4
25	4.76	100	85	8	2.1	87	7	1.8	100	76	6.8	1.8	64	7.2	1.9
30	5.71	100	74	7.2	1.9	74	6	1.5	100	62	7.2	1.9	60	6	1.5
35	6.65	100	64	11	2.9	68	6.4	1.7							
40	7.60	40	60	10	4.2	63	12.5	5							
Right eye.															
10	1.91								50	90	4	1.4	78	3.2	1.2
15	2.86								50	86	7.2	2.7	82	3.2	1.2
20	3.81	60	97	4.5	1.6	89	2.6	.9	50	80	8	3	62	6.4	2.4
25	4.76	60	83	6.6	2.3	83	7.7	2.7	50	78	13.6	5.1	60	8	3
30	5.71	60	80	6.6	2.3	80	6.6	2.3							
35	6.65	60	63	7.7	2.7	63	6.6	2.3							
40	7.60														
Left eye.															
10	1.91								50	88	6.4	2.4	88	10.4	3.9
15	2.86								50	82	6.4	2.4	92	9.6	3.5
20	3.81	60	92	5.6	1.9	92	3	1	50	82	10.4	3.9	66	8.8	3.3
25	4.76	60	90	3.3	1.1	87	4.3	1.5	50	54	11.2	4.2	62	6.4	2.4
30	5.71	60	72	5.6	1.9	80	6.6	2.3							
35	6.65	60	73	7.6	2.6	58	5.6	1.9							
40	7.60														

TABLE VII.—SUBJECT J. S.

Distance in mm.	Distance in degrees.	No. judgments.	Horizontal.				No. judgments.	Vertical.				No. judgment.	Oblique.							
													Up.				Down.			
			Right.		Left.			Up.		Down.			Right.		Left.		Right.		Left.	
			Not seen.	Recognized.	Not seen.	Recognized.		Not seen.	Recognized.	Not seen.	Recognized.		Not seen.	Recognized.	Not seen.	Recognized.	Not seen.	Recognized.	Not seen.	Recognized.
Both eyes.																				
5	.95	30		100		90	20		100		95	10		100		100		100		100
7.5	1.43	20		95		60	20	50	30	60	40	40		95		70		92.5		90
10	1.91	30		77		60						20	45	35	40	35	25	65	65	20
Right eye.																				
5	.95	20		90		80	20		85		80									
7.5	1.43	16	19	70	12.5	60	20	40	25	50	35	20	55	35	25	55	10	60	55	35
10	1.91	20	35	35	45	35														
Left eye.																				
5	.95	20		90	5	80	20		100		80									
7.5	1.43	16	19	56	25	12.5	20	55	25	60	30	20	80	20	65	25	35	45	50	10
10	1.91	20	75	15	40	35														

Table VIII.

Subject.	Percentile limit	Both eyes. Horizontal.		Vertical.		Oblique—Up.		Oblique—Down.		Right eye. Horizontal.		Vertical.		Oblique—Up.		Oblique—Down.		Left eye. Horizontal.		Vertical		Oblique—Up.		Oblique—Down.	
		R.	L.	U.	D.	R.	L.	R.	L.	R.	L.	U.	D.	R.	L.	R.	L.	R.	L.	U.	D.	R.	L.	R.	L.
J. M.	90	33	38	21	25																				
	75			27	33																				
W. R.	90	29	31	20	20	27	23	25	24	30	30	20	18	23	25	22	25	31	29	17	18	20	23	22	21
	75	42	38	24	26	36	40	38	32	35	38	23	24	28	32	35	27	35	35	23	22	28	33	35	30
E. W.	90	25	33							30	21	25						30	30	25					
	75	42	34	26	12					40	23	30	12					35	40	35	12				
S. F.	90	30	30	15	16	22	22	20	23	22	20	13	15	18	20	16	20	17	20	15	15	18	17	17	20
	75	33	34	18	21	27	33	29	32	30	28	21	20	30	30	21	29	29	31	22	20	23	30	25	26
L. W.	90	24	30	13	17					22	20	15	13					20	22	17	15				
	75	34	33	22	25					31	29	18	18					30	31	22	20				
H. W.	90	23	22	17	17					28	23	15	20					25	25						
	75	35	38	25	25					32	35	22	26					35	28	15	15				
G. B.	90	24	26	20	11	20	30	15	15																
	75	32	35	30	19	35	40	23	22																
H. R.	90	20	25	20	15	22	30	21	19	21	23	21	19	20	25	21	20	21	21	21	19	19	23	15	15
	75	31	36	28	23	31	34	24	23	35	35	30	23	27	29	30	23	27	30	24	23	24	28	23	25
H. C	90	20	25							25	20							20	20						
	75	30	37	25	21					35	30							26	35						
A. A.	90	23	20							30								16	16	11	8				
	75	35	32	25	23					33	21	25	23					19	19	13	11				
G. S.	90	23	21	17	17																				
	75	38	26	23	22																				
F. H.	90	22	18	20	15					25			14					30		18					
	75	35	28	26	25					35	25	23	18					38	30	26	18				
W. B.	90	21	21	17	16																				
	75	30	30	26	21																				
V. H.	90									25	25							25	15						
	75	29	30	20	26					33	30							32	20						
P. L.	90	15	20	10																					
	75	26	30	25	17																				
F. C.	90			15								15	15						20	15					
	75	27	26	30	30					20	21	25	18					18	23	30	15				
F. B.	90																	16	15						
	75	25	20	25	25							17	17					20	20	17	20				

Table VI.

Both Eyes.

Distance in mm.	Distance in degrees.	No. judgments.	Horizontal. Right side. Av.	M.V.	P.E.	Horizontal. Left side. Av.	M.V.	P.E.	No. judgments.	Vertical. Up. Av.	M.V.	P.E.	Vertical. Down. Av.	M.V.	P.E.
Subject J. M.															
10	1.91														
15	2.86														
20	3.81	20	100			100			20	95	*5*		100		
25	4.76	30	97	*4.2*		97	*4.2*		50	78	*3.2*	1.2	90	*8*	2.9
30	5.71	60	95	*5*	1.7	97	*4.6*	1.6	50	72	*3.2*	1.2	76	*2.4*	.9
35	6.65	70	86	*10.5*	3.4	92	*7*	2.2	50	58	*3.2*	1.2	74	*2.4*	.9
40	7.60	70	84	*12*	3.8	89	*10*	3.2							
Subject G. S.															
10	1.91														
15	2.86								40	95	*5*	2.1	98	*3.7*	1.6
20	3.81	50	98	*3.2*	1.2	94	*4.8*	1.8	80	88	*3.8*	1.1	86	*6*	1.8
25	4.76	50	86	*4.8*	1.8	76	*4.8*	1.8	80	73	*9.4*	2.8	74	*6*	1.8
30	5.71	50	88	*6.4*	2.4	64	*4.8*	1.8							
35	6.65	50	82	*3.2*	1.2	64	*7.2*	2.7							
40	7.60	20	73	*12.5*		60									
Subject P. L (Chinese).															
10	1.91								80	89	*4.3*	1.3	86	*6.3*	1.8
15	2.86	50	78	*6.4*	2.6	98	*3.2*	1.2	100	80	*8*	2.1	83	*7*	1.9
20	3.81	70	67	*6*	1.9	90	*5.7*	1.8	100	73	*8.2*	2.1	63	*11.6*	3
25	4.76	100	81	*5.1*	1.3	82	*6.8*	1.8	100	78	*6.8*	1.8	57	*9*	2.3
30	5.71	100	68	*6.7*	1.8	74	*6*	1.6							
35	6.65														
40	7.60														

eye separately; in three more these two meridians were explored in both eyes; and in one all four meridians were explored in both eyes. In the remaining seven subjects some data, usually twenty judgments at each distance of the letter from the fixation point, were obtained from the horizontal and the vertical meridians in both eyes, and in each eye separately.

The data obtained in this part of the research are tabulated in Tables I to VIII. Table VIII is essentially an abbreviation of the others, except Table VII, together with the data less thoroughly ascertained. In it only two points in each meridian explored are given for each subject, the point at which ninety percent of his judgments were correct, and at which seventy-five per cent were correct. Where these figures were not given in the data as found, they were determined arithmetically from the percentages on each side. In doing this, it was assumed that the variation in acuity between the two points was uniform. An error resulting from this assumption can be but small, for the points were always slightly less than one degree apart, or five mm. on the card seen in the field.

The tables give the distances of the *n* and the *u* from the fixation point, both in millimeters and in degrees. The number of judgments has reference to the number of *n*'s and of *u*'s distinguished, and the figure in each case applies to two columns of averages. The number of letters distinguished on the right side and on the left side of the fixation point, or above and below, was the same for any pair of corresponding points, hence the numbers needed to be printed but once. One hundred judgments means fifty series, for in each series of cards exposed, both an *n* and a *u* appeared at each point explored.

In addition to the average, both the M. V. and the P. E. are given. In working up the data, the average of ten judgments was arbitrarily, taken as a unit.[1] The variability was therefore not reckoned from as many figures as there were judgments, but from one-tenth as many.

The variability of the averages must be looked upon, in part, not as being due merely to chance, but as the result of observable factors. The chief of these were the condition of the subject and the variability of the retina. The retina fluctuates in sensitivity, a fact noticed by all the subjects. At apparently irregular intervals letters far out appeared as clear as those nearer did at other times. An appeal to eye movements will not explain this phenomenon be-

[1] It seemed that any smaller number would be an inadequate unit, and it may be that twenty judgments would have made a better one than ten. In most instances this would have produced a slightly smaller P. E.

cause the letters appeared clearer in all directions, and the intervals lasted from several seconds to a minute or more.

The retina is also responsive to bodily conditions. So much is this the case that a test like ours might be used to measure a person's physical condition, and, perhaps, fatigue.

The effect this factor had is best illustrated by some results. Subject J. M. worked one day when he was not feeling well. The results from fifty judgments in the vertical meridian for the distances 20, 25, and 30 mm. averaged, above the fixation point, 76%, 76%, and 62% as against 95%, 78%, and 72% at other times; and below the fixation point, 86%, 70%, and 58% as against 100%, 90%, and 76% at other times. The field had contracted fully two degrees. Seven series obtained in the vertical meridian from P. L., while suffering from a cold, averaged 86%, 57%, 71%, and 71% as against 89%, 89%, 73%, and 78% above, and 71%, 43%, 43%, and 64% as against 86%, 83%, 63%, and 57% below. The most conspicuous feature here is the erratic nature of the results obtained when ill. The subject knew he could not see well and that he was guessing, and he asked not to have the results counted. Experience soon taught me not to work with a subject when he was not feeling tolerably well, or when he had been making excessive use of his eyes.

Comparatively little of the variability is owing to the effect of practise. The extents over which the letters could be distinguished 75 per cent of the time in the first twenty series were compared with those in the last twenty series. In eight subjects from whom forty or more series were obtained when looking with both eyes, four had slightly larger extents in the last twenty series than in the first twenty, and four subjects had smaller extents. This was true both in the horizontal and in the vertical directions. In the horizontal direction the average extents increased from 65.6 mm. to 67.4 mm. while in the vertical direction they decreased from 45.7 to 45.2 mm. This indicates that when both eyes were used the effect of practise was nearly, if not quite, zero.

But when the eyes were used singly, practise had some influence. In the horizontal direction six subjects, when using the right eye, uniformly distinguished the letters over larger extents in the last twenty series than in the first twenty, and five out of six did so in the vertical direction. The average extents changed respectively from 61.8 mm. to 69.3 mm. and from 40.9 mm. to 47.3 mm. When using the left eye, four subjects out of six improved in the horizontal direction, and five out of six did so in the vertical direction. The averages changed from 64.4 mm. to 66.3 mm. and from 41.8 mm. to 44.4

mm. This improvement with the single eyes was very likely owing to the fact that the subjects became accustomed to using one eye.

When one eye was used, the view of the other eye was intercepted by means of a black piece of cardboard, which was fastened to the head-rest. It came about an inch in front of the eye and disturbed the subject very little. In fact, after a little practise most of the subjects were seldom conscious of its presence.

The meaning of the averages given in the tables require a word of explanation. They are, of course, not proportional to the visual acuity. A region with a percentage of 75 is not three-fourths as acute as one with a percentage of just barely 100. It is more nearly one-fourth as acute. A percentage of 50 means that the acuity for the units employed is zero. They may still be seen but can no longer be distinguished. Pure guessing should, in the long run, give us that figure.

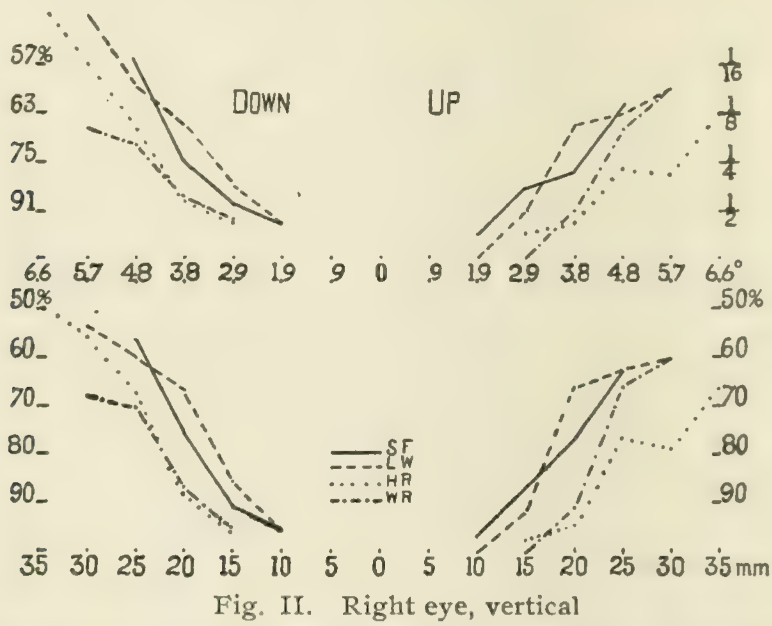

Fig. II. Right eye, vertical

The relation of the acuity of a sense quality to the percent of right cases is given in a table by Fullerton and Cattell.[1] In that table an acuity that gives 75 percent of right cases is taken as unity. Ninety-one percent of right cases indicates an acuity twice as great; 63 percent, about one-half as great; 57 percent, about one-fourth as great; and so on.[2] The steps in acuity between equal differences in the scale of percents are not equal. They are comparatively short in the region of seventy-five percent and longer toward both extremes.

[1] *The Perception of Small Differences*, Phila., 1892, p. 16. The table is reproduced by Sanford, *Experimental Psychology*, p. 354; and by Thorndike *Mental and Social Measurements*, p. 164.

[2] The validity of this relation has not been fully demonstrated empirically.

A few illustrations of the relation between the retinal acuity and the corresponding percent of right cases found in our experiment are shown graphically in Figures II, III, and IV. These figures correspond to the size of the field as found. The abscissae indicate the deviations from the fixation point, given in millimeters in the lower

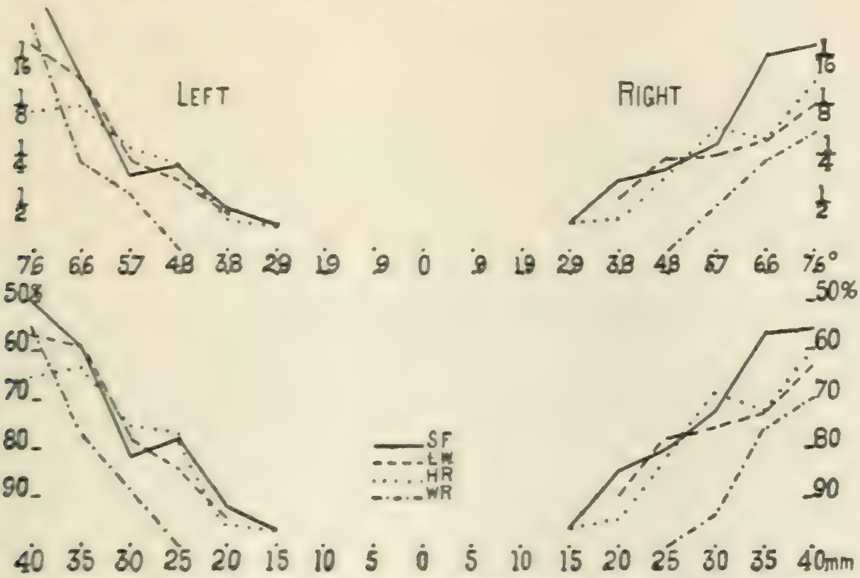

Fig. III. Left eye, horizontal

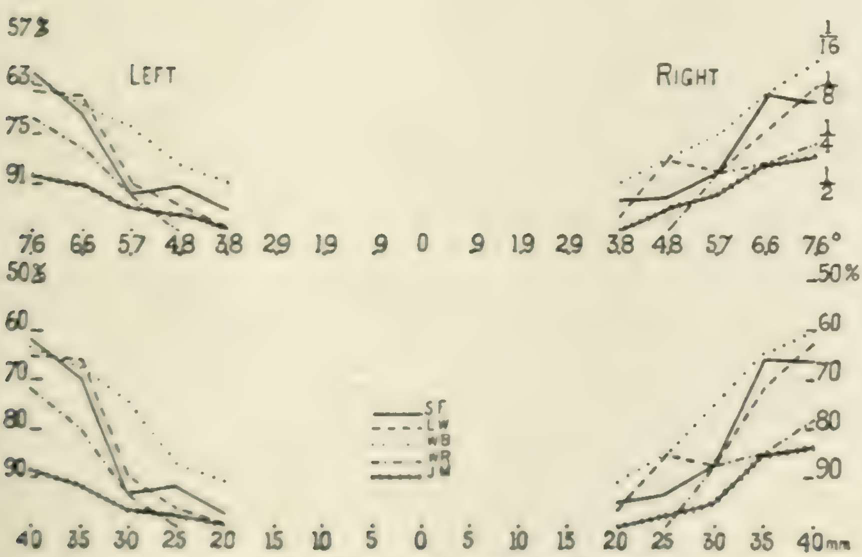

Fig. IV. Both eyes, horizontal

half of the figures and in degrees in the upper half. The ordinates in the lower part of each figure are marked off in equal steps corresponding to the decrease in percent of right cases, and in the upper part they are marked off in equal steps corresponding to the decrease in retinal acuity. The acuity, just keen enough to distinguish the letters, is here taken as unity. The determinations from four sub-

jects, right eye, vertical meridian, are plotted in Figure II; those from four subjects' left eye, horizontal meridian, in Figure III; and those from five subjects' both eyes, horizontal meridians, in Figure IV. No striking differences between the lines in the upper and the lower part of the figures are manifest. The lines in the upper part are more nearly straight than those in the lower part, which indicates that, as one goes out from the fovea, the retina loses its acuity in the main gradually.

When comparisons are made between the lines themselves, and between those coming from different subjects, certain differences become apparent.

The lines coming from the different subjects ascend with unequal rapidity, indicating different modes of decrease in retinal acuity. This is illustrated in Figure IV by subjects J. M. and W. R. and other illustrations may be found in the tables. No doubt there is here a normal variation from a small to a large indistinct field.

When the lines are compared among themselves it is noticed that some descend to points lower than they have already attained. This indicates a higher percentage of right judgments, and consequently a gain in visual acuity, as a point farther from the center of the fovea is reached. Where the descent is small it may be owing to chance, but this is certainly not always the explanation. The subjects were usually distinctly aware of the fact that there were places at which they could not see well.

About half of the subjects felt that it was more difficult to distinguish the letters 20 or 25 mm. from the fixation point than at the next distance farther out, and this shows in the results. Nearly all the regressions in Figures II, III, and IV, for example, occur between 25 and 30 mm. from the center. When the letter was 25 mm. from the fixation point, its image fell approximately one millimeter from the center of the fovea, a distance corresponding closely to its radius.[1] There is a depression in the yellow spot about the fovea centralis, and it may be that the slope of this depression is less acute than points just beyond. This might well be, because an image falling on this slope would be somewhat distorted. The reason why an irregularity corresponding to this point does not appear in all the records may be found in the fact that all the points in any one meridian were not explored, so that in some instances no image might have happened to fall on this slope. Then, too, the slope is more abrupt in some people than in others.

[1] Dimmer, *Anatomie und Physiologie der Macula Lutea*, Leipzig und Wien, 1894, p. 6.

Aubert and Foerster, when exploring their retinas, found a number of small blind spots at various distances from the center of the fovea.[1] These did not fall in the zone indicated above, and must be looked upon as imperfections in the retina. I also found such imperfections, but they could seldom, if ever, be called blind spots. They were, however, more pronounced than those already mentioned.

One of these spots occurs in the data obtained from the writer. It is in the right eye, oblique down, on the right side, 30 mm. or 5.71 degrees from the fixation point. The judgments based upon letters appearing there seemed to me to be guesses. Although the spot is in the right eye only, it showed in the data obtained with both eyes. Here an effort was made to eliminate it by taking extra data, but without success.

The most pronounced retinal irregularities were found in F. B., V. H., and E. W. When working with the right eye, F. B. could not see the letters at all on the left side beyond 15 mm., or about 3 degrees, from the fixation point. About 10 percent of the time, he thought he saw a slight blurr, but nothing sufficient for identification.

V. H. had a similar condition in the left field of the left eye, but slightly less pronounced. At 25 mm. out he still saw enough to venture a judgment, which, however, was just as likely to be wrong as right. But beyond that distance he got even a faint impression only about half the time. On the right side the field was normal, reaching a percentage of 75, approximately 30 mm. from the fixation point. E. W. apparently had two variations, including both the left and the right sides of the left eye. At 25 mm. the keenness of vision was much reduced, while at 30 mm. it was about as keen again as at 20 mm. The percentages of right cases from twenty judgments at 20, 25, 30, and 35 mm. were on the right side respectively 90, 75, 90, and 75, and on the left side 95, 50, 90, and 75.

The individual differences in the areas mapped out are of various kinds. It has already been pointed out that there are variations in the manner in which the acuity falls off as one recedes from the center of the fovea. In some people this falling off in acuity is less rapid than in others, giving them a relatively large field of indistinct vision. This fact makes it difficult to arrange the areas of the various subjects in order according to size. The order is slightly different when based upon the 90 percent boundary as when based upon the 75 percent, boundary. The irregularities or 'blind spots' which exist in some retinas and not in others may also be looked upon as individual differences.

[1] *Physiologie der Netzhaut*, p. 246.

An inspection of Table VIII shows that, when both eyes were used, the horizontal extent in the limits of which the letters were rightly distinguished 90 per cent of the time varies from 35 to 71 mm. This is a variation approximately as 1–2. In the vertical direction the corresponding variation is from 31 to 46 mm., or approximately

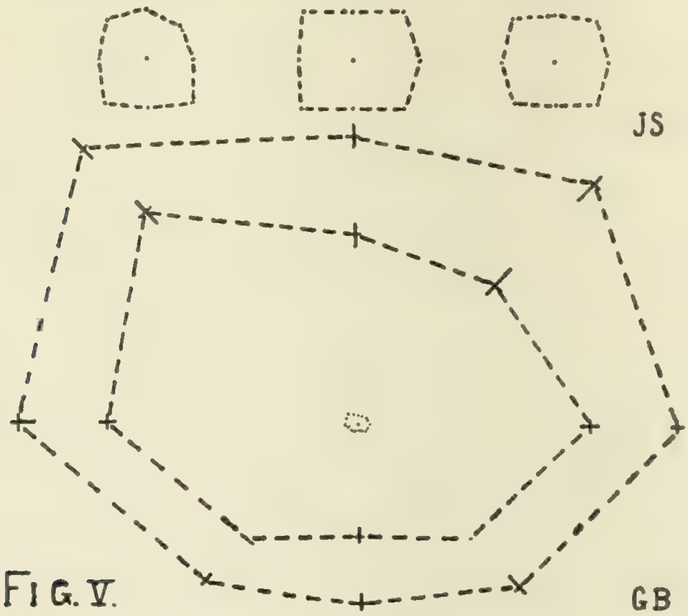

FIG. V.

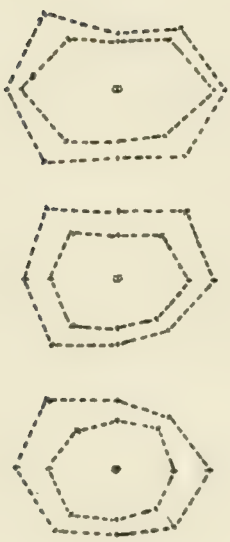

FIG. VI SF

FIG. VII HR

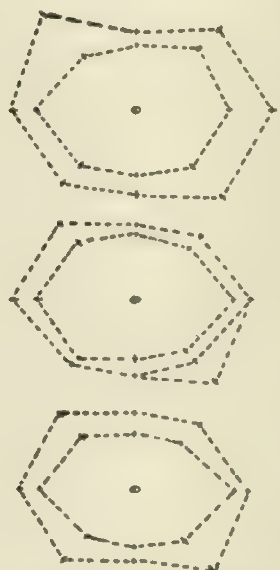

FIG. VIII WR

as 1 to 1.5. If the area that had the longest extent horizontally had also the widest extent vertically, the variation in area should be as 1–3. But this is not true. The longest area is not necessarily the widest, and vice versa. When the two diameters are multiplied together the extreme products are 1386 and 3266, showing a variation of 1–2.3. In these comparisons the data from J. S. are not included.

His areas, as may be seen in Figure V, are abnormally small and so should be considered in a class by themselves.

Some of the variations in the shape of the areas are brought out in Figures V–VIII. The data on which these figures are based came from Table VIII. The diagrams in Figure V represent the actual size of the fields as mapped. The large diagram is a medium-sized field coming from G. B. when using both eyes. The small field at the center shows the area covered on the retina by the 90 percent. limit. The small figures above this one represent the fields within which J. S. could distinguish the letters 90 percent of the time. The one in the center comes from both eyes, the one to the left from the left eye, and the one to the right from the right eye. The right-hand side of all these figures represents the right-hand side of the field.

Figures VI, VII, and VIII are reduced to one-third actual size. The top one in each case comes from both eyes, the middle one from the right eye, and the bottom one from the left eye. As would be expected, the field for both eyes is, as a rule, larger than that for either of the single eyes. The inner line represents the limit where the letters were named correctly 90 percent of the time, and the outer line where they were named correctly 75 percent of the time. Only the points in the horizontal, the vertical, and the oblique meridians midway between these were determined, of course. The short lines parallel to the radii crossing these points correspond to the P. E. The chances are even that the true position of this point may fall anywhere on this line. The double line in the middle diagram of Fig. VIII is the result of the spot mentioned above. Between the two determinations the percentages fell below 75, thus giving two points having that figure.

The small field at the center of each diagram again represents the area covered on the retina by the 90 percent limit, reduced in the same ratio as the diagrams. It was determined by assuming that the rays of light cross 15.6 mm. in front of the retina.[1] The horizontal diameter of this area varies from 2 to 3 mm., or taking all our data, from 1.5 to 3 mm. This is larger than the corresponding diameter of the fovea as found by Dimmer. He found in ten careful measurements a variation from 1.1 to 2 mm.[2] There is no abrupt fall in visual acuity when one passes beyond the limits assigned to the fovea.

The shape of the field of acute vision varies from an oblong nearly twice as long as wide, to a circle. The oblong, however, approximates more to the shape of a rectangle than to that of an oval. This

[1] Sanford, *Experimental Psychology*, p. 107.

[2] *Op. cit.*, p. 6.

form evidently corresponds to the shape of the fovea. In the words of Dimmer, "Die Fovea ist eine meist querovale, oft aber auch kreisrunde Vertiefung."[1] With this description the shapes of the accompanying diagrams agree. That of G. B. is slightly oblique, a position the fovea has also been observed to take.[2]

An attempt was made to ascertain the shape of the fovea by means of an ophthalmoscopic examination, but with only limited success. The fundus of the right eye in five subjects was examined.[3] The retina of J. S., whose field of distinct vision was found to be abnormally small, was immediately pronounced pathological by the examiner. A well-marked white spot indicating the position of the fovea centralis was present, but this was surrounded by excessive and irregular pigmentation, and the adjacent fundus was mottled. Beyond the pigmentation the retina was marked with Tay's spots, which indicate a pathological condition that usually comes on in old age and is seldom seen in a person of the age of J. S.

The depression surrounding the fovea centralis appears ophthalmoscopically slightly darker than the adjacent fundus, owing to the fact that because of the slope of the sides it reflects less light to the examiner's eyes. The dark area corresponding to this depression appeared circular in H. R., which is practically the shape of her field. In the center of the area appeared a crescentic white spot. Unfortunately, the dark area was not distinct enough to be assigned a definite shape in the remaining three subjects. None whatever could be seen in the eyes of J. M. and W. R., and in S. F. it was extremely small. The fovea centralis was marked in J. M. by a minute whitish spot with only a trace of pigmentation about it, while there were no such spots observable in the eyes of S. F. and W. R. Pigmentation nearly circular in form was present in W. R., but none could be made out in S. F.

Wertheim[4] found that beyond 15 degrees from the fixation point the field of indirect vision resembled that of the color zones. He said "the acuity of vision decreases most rapidly above; a little less rapidly below; still more slowly on the medial side; and most slowly on the lateral side." Within 15 degrees, however, he found practically no difference between the lengths of the lateral and medial radii

[1] *Op. cit.*, p. 13.

[2] Norris and Oliver, *System of Diseases of the Eye*, Philadelphia, 1897, Vol. I, p. 328 (Piersol).

[3] The examination was kindly made by Dr. W. A. Holden, of the College of Physicians and Surgeons, New York.

[4] *Zeitsch. f. Psych.*, Vol. VII, pp. 184.

and between that of the upper and the lower. This conclusion is substantiated by my results. There are no pronounced constant differences between these two pairs of radii revealed in my data.

It was thought that the habit of looking and attending to the right in reading might tend to make the field on that side larger than on the left side. But no such constant difference was found. When both eyes were used together the field was quite as likely to be a little larger on the left side as on the right. Averaging the distances of the 90 percent and the 75 percent limits from fourteen subjects gives 28.3 mm. for the right side and 28.8 mm. for the left. There seems, however, to be a tendency for the field to be slightly larger on the right side for the right eye, and on the left side for the left eye. This is the outer field and corresponds to the deviation in the field of vision as a whole. In eight subjects who had no conspicuous retinal defects and from whom sufficient data were obtained, only one had a slightly larger left field in the right eye, and three had a slightly larger right field in the left eye. The averages for the eight are respectively for the right and the left fields, 30.2 mm. and 27.5 mm. for the right eye and 26 mm. and 27 mm. for the left eye. The differences are small and might disappear with data from more subjects, but they are suggestive. They might here be explained by the fact that the eye was always a little nearer to the letters in the outer field than to those in the inner field, and for that reason they could be distinguished more readily.

An examination of Table VIII reveals somewhat larger variations in the vertical meridian than in the horizontal meridian. Some subjects could see considerably farther out on one side of the fixation point than on the other, but no significant constant tendency is discernible. For the right eye (six subjects) the average extent of the field is .4 mm. greater downward, while for the left eye and for both eyes (ten subjects) it is approximately 1 mm. greater upward. No significance can be attached to these figures. The deviation occurs in one direction just about as often as in the other.

It was the original intention to get data also from members of races other than the Caucasian so that interracial comparisons might be made, but it did not prove practicable to do this to any great extent. Subject P. L., whose data are tabulated in Table VI, is a Chinese. His area is among the smallest I found, but one can draw no conclusion from this in regard to race differences. His eyes are somewhat defective, which probably accounts for his limited field. Data obtained in the preliminary experiments from another Chinese and from a Japanese go to show that the Mongolian race is at no advantage

in the size of the acute field. The Chinese gave indications of having a field of about average extent, while that of the Japanese was considerably above the average. It would probably have taken rank among the upper fourth or fifth.

Notice may be taken at this time of the data obtained from J. S. He has been referred to a number of times as having an abnormally small distinct field. He could distinguish the letters even when using both eyes within a total visual angle of scarcely 1.5 degrees. The average for the other subjects was about 10 degrees. When using one eye his angle shrank to about one degree. The field that this indicates would be represented on the retina by a spot approximately .23 mm. in diameter. This corresponds closely to the dimensions assigned to the fovea centralis, or foveola, which, according to Dimmer,[1] varies from .12 mm to .3 mm in diameter. It seems then that we have here a case in which distinct vision is limited to the foveola.

The data obtained from this subject are tabulated in Table VII. Decisive judgments were as a rule always demanded of a subject, for only right and wrong judgments were recorded. But here it was thought wise to deviate from that rule, for when J. S. did not recognize a letter he usually had seen nothing of it, so that he could not tell even in which direction from the center it lay. After the data in the horizontal meridian had been obtained, a record of the letters not seen was kept, and appears in the table. He frequently said that he saw only half of the letter, which indicates that his boundary line of distinct vision is extremely sharp.

The occasional recognition of letters beyond what appears to be his limit may be explained by small eye movements. Fixation is seldom, if ever, entirely steady.[2]

Although with an exposure time of 50 sigma, this subject could not tell even in which direction a letter lay, whose line of direction made an angle of 45 minutes or more with the line of sight, he was at no corresponding disadvantage in other visual tests. He himself had not known previous to these tests that he had a constricted field. He could distinguish buildings and a waving flag about as far from the fixation point as other people, and he was at no apparent disadvantage in seeing the carrier on the perimeter at 90 degrees in the outer field. His color zones were the smallest I found, but they formed no break in series with those of the other subjects. His visual acuity was fully up to the average. He is a slow reader and makes

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[1] *Op. cit.*, p. 14.

[2] Cf. C. N. Mc Allister, 'Points of Fixation in the Visual Field', *Psych. Rev.*, Mon. Sup. Vol. VII, No. 1, pp. 17–54.

many eye movements per line, but in neither of these characteristics did he take lowest rank.

After the foregoing data had been collected, an attempt was made to standardize the unit of vision that was used. I aimed to draw a hook that would give approximately the same results as the

TABLE VIII A

			Horizontal.											Vertical.									
			Both eyes.																			
			Hooks.				Letters.					Hooks.					Letters.				
			Right		Left.			Right.		Left.			Up.		Down			Up.		Down.	
Distance in mm.	Distance in degrees	No. judgments	Av.	Mv.	Av.	Mv.	No. judgments.	Av.	Mv.	Av.	Mv.	No. judgments.	Av.	Mv.	Av.	Mv.	No. judgments.	Av.	Mv.	Av.	Mv.
S. F.																					
20	3.81											50	86	7	80	4	30	90	7	83	4
25	4.76											50	78	6	76	7	30	83	9	87	9
30	5.71	30	93	9	83	4	20	85	5	85	5	50	74	8	56	7	30	70	7	50	0
35	6.65	30	73	12	73	12	20	70	0	70	10										
W. R.																					
20	3.81											70	93	10	93	6	70	89	8	94	5
25	4.76											70	79	12	84	8	70	76	8	80	11
30	5.71	40	95	5	100	0	40	100	0	95	5	70	76	9	71	7	70	73	10	76	5
35	6.65	40	93	8	93	8	40	93	8	85	5										
H. R.																					
20	3.81											80	88	8	88	6	60	90	7	83	7
35	4.76											80	83	9	81	6	60	79	5	71	12
30	5.71	30	60	7	77	16	20	95	5	90	0	80	70	15	58	9	60	66	7	56	7
35	6.65	30	63	4	77	16	20	90	0	75	5										

n and the *u*. After a number of failures, closely corresponding results were obtained with a hook that was essentially a square with one side open, having a length of side of one millimeter. The horizontal line in the letters was lighter than the vertical lines, and therefore harder to see, while in the hooks the lines were all of equal weight. This made it necessary to make the hooks smaller than the letters.

The hooks were drawn with a fine (Gillott 170) pen, and black India ink, and the lines were about two-tenths of a millimeter wide. The hooks were faced like the *n* and the *u*, one up and one down, and were exposed in the same manner. Data were obtained from three subjects. So as to make the comparison entirely fair, the letters were exposed alternately with the hooks. Five series of hooks were exposed and then five series of letters.

The results are condensed in Table VIIIA. With the exception of one record, that of H. R. horizontal, the correspondence between the hooks and the letters is fairly close. In fact, it is just as close as the correspondence between the records obtained with the letters in the former tests and that obtained with the letters here.

It is worth noting that the discrepancies between the two records obtained with the letters are not always within the probable error. They are more nearly within the mean variation. This agrees with the observation made by Professor Cattell, namely that the P. E. gives us a higher degree of certainty than is warranted. It should probably be interpreted to mean that it would apply if the determinations could be actually repeated.

PART III—CORRELATIONS

A knowledge of the relationship between facts is as valuable as a knowledge of the facts themselves, and frequently more so. It is for this reason that a large share of the time given to this study was devoted to the ascertaining of relationships. In addition to the extent of the field of acute vision, a number of other items were also obtained from each subject, and these have been correlated among themselves in various ways.

In the following pages usually two numbers are given to express each correlation. One of these is the Pearson coefficient of correlation and the other is the percent of displacement.

The Pearson coefficient is now so generally understood that the method of obtaining it need not be given.[1] "It expresses the degree of relationship from which the actual cases might have arisen with least improbability. It has possible values from +100 percent through 0 to—100 percent. A coefficient of correlation between two abilities of +100 percent means that the individual who is the best in the group in one ability will be the best in the other, that the worst man in the one will be the worst in the other, that if the individuals were ranged in order of excellence in the first ability and then in order of excellence in the second, the two rankings would be identical, that any one's station in the one will be identical with his station in the other (both being reduced to terms of the variabilities of the abilities as units to allow comparison). A coefficient of —100 percent would per contra mean that the best person in the one ability would be the worst in the other, that any degree of superiority in the one would go with an equal degree of inferiority in the other, and vice versa. A coefficient of +62 percent would mean that (comparison being rendered fair here as always by reduction to the variabilities as units) any given station in the one trait would imply 62 hundredths of that station in the other. A coefficient of —62 would of course mean that any degree of superiority would involve 62 hundredths as much inferiority, and vice versa."[2]

A method of expressing relationships by means of the percent of displacement has recently been advanced by Professor R. S. Woodworth.[3] It is simpler than the Pearson coefficient and gives results

[1] For an exposition of this method see Thorndike, *Mental and Social Measurements*, Chapter IX.

[2] Thorndike, *Educational Psychology*, p. 26.

[3] Unpublished.

in a much shorter time. It takes into consideration only the relative position of the measurements compared, and notes the amount of agreement or disagreement in the orders.

1	E. W.	2	
2	A. A.	10	
3	H. W.	1	2
4	F. H.	6	1
5	S. F.	4	2
6	H. R.	7	1
7	L. W.	5	3
8	H. C.	9	1
9	W. R.	3	6
10	F. C.	8	2
			18

$$\frac{(n-1)n}{2}=\frac{(10-1)10}{2}=45$$

$18 \div 45 = .40 = 40$ percent of displacement or transposition

The manner of finding the percent of displacement may be illustrated by means of two orders from among my determinations. The column of initials is a serial arrangement of ten subjects according to the extent of the color zones in the left eye. The numbers in the next column indicate the rank of the same ten subjects when arranged according to the visual acuity of the left eye. Clearly the subjects do not take the same order in the two traits. The amount of displacement between the two orders may be noted in the column of figures standing for the rank in acuity. The first figure, 2, does not follow a larger number than itself, and the next number, 10, does not; 1 follows two numbers larger than itself; 6 follows one; 4, two and so on. The amounts the different numbers are displaced are given in the last column. They give a sum of 18.

The total amount of displacement possible may be found according to the formula $\frac{(n-1)n}{2}$, in which n stands for the number of cases compared. Applying this formula here gives us 45; and dividing 18 by 45 gives us .40, the percent of displacement.

It may now be readily understood what correlations the different percents of displacement signify. A zero percent signifies perfect relationship. The person who is best in one trait is also best in the other, and the poorest in one is also poorest in the other. A displacement of 100 percent signifies complete antagonism. A person who is best in one trait is poorest in the other, and vice versa. No relationship is indicated by a displacement of 50 percent. This means that nothing can be predicted from a person's rank in one trait about his

rank in the other trait with which the first has been compared. Percents of displacement between zero and fifty indicate relationships that decrease as the percents increase. Percents of displacement between fifty and one hundred indicate antagonisms that increase with the percents.

Correlation determined by the percent of displacement takes into consideration only the relative position of the measurements compared. The amount of deviation above or below the average does not enter into the calculation. When the number of measurements is large, this is a disadvantage, and the Pearson coefficient which is sensitive to amount of deviation, is more accurate. But when the number of measurements is small, as most of mine are, this is an advantage. It is not distorted by extreme deviations, as the Pearson coefficient is likely to be. It has an advantage over the Pearson coefficient similar to that possessed by the median over the average. The number of measurements compared in the tables that follow being comparatively small, I feel that the percent of displacement is the safer figure to accept when there is a discrepancy between the correlations obtained by the two methods. I found in an extreme case, for example, a Pearson coefficient of −.27 and a displacement of 49 percent when ten measurements were compared, one of which deviated excessively from the average. Omitting this case, the Pearson coefficient became −.31 and the percent of displacement 61.

Illusion of Square and 'Golden Section.'

The first correlations considered are two with the shape of the field of distinct vision as a whole. They were made between the oblongness of the field and the illusion in the perception of distances depending on their direction in the field of vision, and the variation in the choice of a 'golden section.' People usually overestimate vertical as compared with horizontal lines, but the amount of illusion differs for individuals; and the ratio of height to length of a rectangle that is preferred varies with different people. It was thought that these variations might bear a relation to the variations in the shape of the field of distinct vision. A highly oblong field might, for example, exaggerate the overestimation of vertical lines because it would necessitate greater eye movements to bring objects in the vertical plane to clear vision than would be necessitated by a less oblong field. The shape of the rectangle preferred might correspond to the shape of the field of vision because it might be most agreeable to have the two fit together.[1]

[1] A suggestion made by Professor Cattell

The illusion of vertical as compared with horizontal extents I tested with rectangles. I had twenty-eight of these drawn on a sheet of paper which was pasted on the wall directly in front of the subject. The rectangles were all 20 mm. wide, but varied from 15 to 25 mm. in height, six of them being true squares. The subject was requested to designate by number all those that *looked* to him to be square. He was warned not to allow his knowledge of the illusion to influence his judgment. Data were obtained from ten subjects, and from five to eight figures were designated by each. These differed in height, and the average of the heights of all was taken as a person's measure. The averages were then compared with the ratios of the vertical to the horizontal diameter of the field of distinct vision. The percent of displacement between the two orders was 42, and the Pearson coefficient +.10. If any correlation exists, it is evidently slight.

In the choice of a rectangle of preferred proportions, two tests were made. One of these consisted of making a selection from a chart containing thirty-six figures which varied from 35 to 105 mm. in height by 100 mm. in width. The chart was suspended on the wall and the subject was about twenty feet away when he chose. The other test consisted of making a selection from a set of nine rectangles cut from cardboard. These also were 100 mm. wide and varied from 25 to 100 mm. in height. The subject was close to them when he chose and was permitted to handle them.

Ten subjects took part in the tests. The selections from each set were made independently of each other, usually several days apart, so that when the second selection was made the subject had forgotten what ratio of sides he had chosen in the first. Although most of the subjects had no pronounced preference for any particular shape, regarding it as largely a matter of caprice which they chose, the correlation between the two selections was high. There was a displacement between them of only 15 percent.

The ratio of the height to the width of the rectangles chosen varied from .57 to .96 on the chart, and from .5 to .8 with the cards. These ratios were compared with the ratios of the vertical to the horizontal diameters of the field of vision, a separate comparison being made for each of the two tests. The percent of displacement with the cards was 55 and that with the figures on the chart was 40. The Pearson coefficient in the second case was +.34, but it is not reliable, the positive amount all being caused by the extreme deviation of one case. The number of positive and negative ratios was the same. Had any pronounced positive or negative correlation been indicated I should have corrected for attenuation, but this did not seem necessary under the circumstances.

The number of cases compared was small, but the variations were so haphazard that I feel a high degree of confidence in the conclusion that there is little or no correlation between the oblongness of the field of vision and the shape of rectangle preferred. A person with a long and narrow field is just about as likely to prefer a rectangle of opposite proportions as one of the same proportions as his field. The source of the preference must be looked for elsewhere. It is very likely central in the main, and may in part be owing to acquired associations.

Color Zones.

The color zones were mapped with a McHardy perimeter. The work was done near a large window and a stimulus area of 1 sq. cm was used. Various colors were tried, but it was finally decided to use the ones on the perimeter. Difficulty was experienced with the yellow and the green. With the area used, these colors could not be seen out as far as the blue and the red respectively. The blue and the red, however, gave satisfactory results, and as the zones for them coincide with those of the yellow and the green respectively,[1] the latter were dropped from the experiment.

Four radii, the horizontal and the vertical, were explored in each eye. As a rule only one determination was made with each subject, but the various colors were presented from three to ten times in each radius, or until both the operator and the subject felt that the most likely limit had ben established. A second determination was made for two of the subjects and the results compared with the first. The discrepancies between the two determinations were slight. Still, it must be admitted, that the ordinary perimeter is not adapted to give results of any high degree of precision. What we should have is a perimeter by means of which we could expose one of several colors in the two opposite radii for a space of time less than the reaction time of the eye. This would eliminate eye movements and allow the method of right and wrong cases to be applied.

The figures standing for the extension of the color zones in degrees are given in Table IX. The arrangement of the figures corresponds to their position in the field. The left-hand figure indicates the extension in the left field; the right-hand figure, the extension in the right field; the upper figure the extension in the upper field; and the lower figure the extension in the lower field.

The correlations between the extension of the color zones and other phenomena of vision are condensed in Table X. First the absolute diameters both in the horizontal and in the vertical directions

[1] J. W. Baird, *Color Sensitivity of the Peripheral Retina*, 1905, p. 61.

were compared for both eyes working together. The color zones were, of course, determined only for each eye separately, but as the vision of both eyes is fully equal to that of the better single eye, the longer diameter was uniformly chosen when there was a difference in the two eyes. It should be noted further that as two limits were determined in each of the two cases compared,—one for the blue and one for the red in color, and that for the 90 percent limit and that for the 75 percent limit in vision,—the average of the two was used in these and in the following comparisons whenever possible. The areas

TABLE IX.—COLOR ZONES.

	Left eye.		Right eye.			Left eye.		Right eye.	
Subject	Blue.	Red.	Blue.	Red.	Subject.	Blue.	Red.	Blue.	Red.
E. W.	31 85 49 58	30 80 35 45	30 56 85 57	30 32 85 46	V. H.	36 87 43 60	28 80 32 36	40 49 88 64	28 32 65 34
A. A.	48 82 61 80	53 80 56 70	54 67 81 75	50 65 78 60	L. W.	35 84 48 67	24 83 27 48	35 45 86 67	26 20 78 49
G. D.	35 82 58 72	32 78 45 57	36 58 85 70	31 45 80 60	H. C.	37 80 47 68	29 75 33 41	38 47 78 67	29 33 66 40
F. H.	50 86 61 68	38 85 27 48	40 41 85 63	33 27 81 45	F. C.	35 80 45 55	18 70 35 38	35 46 84 60	25 28 70 45
P. L.	31 85 49 58	30 80 35 45	30 56 85 57	30 32 85 46	G. B.	42 78 54 58	26 67 25 30	44 45 79 63	31 31 68 32
H. W.	40 85 40 73	36 75 40 58	47 50 85 73	45 40 83 54	W. B.	34 86 36 51	28 78 23 36	33 30 86 52	22 28 62 32
H. R.	38 88 50 68	29 85 40 35	38 55 88 71	35 38 73 54	J. M.	37 83 40 52	24 67 25 30	38 40 80 45	23 24 52 28
S. F.	45 88 47 64	32 75 34 45	45 43 86 65	33 29 80 48	F. B.	35 84 43 40	22 51 30 31	35 42 84 46	28 32 50 33
W. R.	37 82 54 62	28 70 36 39	37 51 88 61	29 34 76 35	J. S.	30 71 42 47	16 65 25 27	30 38 69 53	18 22 45 31

of the color fields were accordingly found by multiplying the average of the number of degrees of the blue and of the red in the horizontal meridian by the average of the corresponding numbers in the vertical meridian. Similarly the areas of the fields of acute vision was found by multiplying together the average diameters in millimeters. This gave equal weight to each of the two determinations that entered into the comparisons.

TABLE X.—CORRELATIONS WITH COLOR ZONES.

		No. of cases compared.	Percent of displacement.	Pearson coefficient.
Color and vision,—horizontal	Both eyes	16	42	—.01
" " " vertical	" "	16	58	—.36
" " " areas	Right eye	10	35	
" " " "	Left "	10	49	
Color $\frac{\text{right}}{\text{left}}$ and vision $\frac{\text{right}}{\text{left}}$	Right eye	11	60	—.48
" $\frac{\text{left}}{\text{right}}$ " " $\frac{\text{left}}{\text{right}}$	Left "	11	62	—.33
" $\frac{\text{U}}{\text{D}}$ " " $\frac{\text{U}}{\text{D}}$	Right "	10	49	+.27
" $\frac{\text{U}}{\text{D}}$ " " $\frac{\text{U}}{\text{D}}$	Left "	10	42	+.30
Color area and visual acuity	Right eye	10	49	
" " " " "	Left "	10	40	

The Pearson coefficients found in this comparison are —.06 and —.36 respectively for the horizontal and the vertical meridians. The percents of displacement are 42 and 58, showing respectively a slight positive and a slight negative relation. The figures, however, all hover close to the point of no correlation, and this is most likely what they should be interpreted to mean.

The next correlation was made between the areas of the two fields. This was done separately for each eye. The figures compared were obtained, as indicated above, by finding the products of the horizontal and the vertical meridians. These evidently do not give the areas exactly, but they are very nearly, if not entirely, proportional to them and as my comparisons touched only their order in size, they were sufficiently exact. Only the percentages of displacement were found. They are respectively for the right and for the left eyes 35 percent and 45 percent, again showing but a slight degree of relationship.

So as to make the test of relation more refined, the ratios of the corresponding radii were correlated. Even though there is little or no correlation apparent when the absolute numbers are compared, a relation might still exist between the variations in the extensions of the two fields in the different directions from the center of the fovea. This relation might hold even though there was no relation between the sizes of the two areas themselves.

In the vertical meridian I compared the ratios of the upper to the lower radii, and in the horizontal, the ratios of the outer to the inner. As is shown in the table, slight positive relations are indicated in the first case and slight negative relations in the second. This is true of both the Pearson coefficient and the percentages of displacement. But the relations indicated are again not large enough to be significant. This is especially true of the percentages of displacement, which must here be considered the most reliable because they are not influenced by extreme deviations as the Pearson coefficients at this point clearly are. These percentages all hover close about the "50" point, which is the figure that stands for no correlation.

Between the areas of the color zones and visual acuity there is also little or no correlation. The percentages of displacement are 49 for the right eye and 40 for the left. This lack of correlation indicates that there is litttle or no connection between keenness of color vision and other qualities of sight. This harmonizes with the common observation that a person with defective color vision is at no disadvantage in tests of vision that do not involve color. But the conclusion cannot be accepted as final because, as far as I am aware, the relation between the keenness of color vision and the extension of the color zones has not been investigated.

Retinal Sensitivity, or Inertia.

Another item determined in most of the subjects was the sensitivity of the retina. Cattell[1] found with three subjects that the time necessary for a printed character to act on the retina in order to be recognized varied from .75 to 1.75 sigma. It was about 25 sigma shorter by clear daylight than by lamplight, and about 25 sigma longer for subject C than for B, and again about 25 sigma longer for H.

The data obtained are tabulated in Table XI. They were determined by means of the fall-screen. The aperture used was 2.5 mm. wide, except in two cases where it was 5 mm. wide, the smaller aperture not giving a long enough exposure time. The smaller aperture was approximately as wide again as the letter *n*, and wide

[1] 'Ueber die Trägheit der Netzhaut und des Sehcentrums,' *Philosophische Studien*, Vol. III, p. 110.

TABLE XI.—RETINAL SENSITIVITY.

Subject.	Both.	Right.	Left.
J. M.	.49	.63	.67
H. R.	.49	.63	.67
L. W.	.51	.67	.59
S. F.	.53	.63	.63
H. C.	.56	.63	.90
W. R.	56	.72	.79
F. C.	60	.67	.67
E. W.	.60	.72	.72
H. W.	.60	.72	.90
G. S.	.63	.72	.79
W. B.	.67	1.02	1.02
F. H.	.72	.79	.90
G. B.	.79	.90	1.02
J. S.	90	1.14	3.82
F. B.	1.14	1.14	2.10
A. A.	1.57	2.55	2.55

enough to allow any of the letters used to be seen entirely at once. The exposure time was regulated by changing the length of the fall. It was calculated by means of the formula for accelerated motion, the accelerating force being gravity. The time it took the screen to fall 2.5 mm. with the speed it had attained when half the letter was exposed was found. This did not take into account the fact that the speed increased a little between the beginning and the end of the exposure, an error that is just about counterbalanced by the slight friction of the apparatus.

The exposure times given in the table are in sigma. They probably cannot be taken at their face value because, the background being dark, after-images were not excluded, and so prolonged the impression. The figures given are the times that were necessary for the subjects still to distinguish the *n* and the *u* about 90 percent of the time when these letters were exposed in chance order with six others, some of which were easier and some harder to see. Those that were harder to identify were especially the *c* and the *e*. It was the aim to decrease the time till these letters no longer could be distinguished while the *n* and the *u* still could be. This method was rapid and proved quite satisfactory.

All the determinations were made between one and three in the afternoon and only when the sky was clear. Even slight cloudiness made a longer exposure time necessary, and the retinas of several subjects were noticeably more sensitive in the forenoon than in the

afternoon. The sensitivity is also reduced about one-half when the eyes are tired from reading as compared with when they are rested. This influence we guarded against by making the determinations only when the subjects had not read much that day, and by repeating them on different days.

The correlations that were made are shown in Table XII. All the figures indicate positive relations, but none of any pronounced

TABLE XII.—RETINAL SENSITIVITY CORRELATED WITH:

		No. of cases compared.	Percent of displacement.
Area of distinct vision	Both eyes	15	27
" " " "	Right eye	10	44
" " " "	Left "	10	47
Visual acuity	Both eyes	15	41
" "	Right eye	16	32
" "	Left "	16	27

degree. The correlations for acuity and sensitivity are lowered by the presence of two near-sighted people. The defect influences acuity but not sensitivity. When the data from these people are excluded from the comparisons, the figures 41, 32, and 37 become respectively 33, 25 and 31. It is my impression that if defective eyes were excluded and more data were gathered, and with more care than I had time to give to this point, decisive correlations would be revealed.

Visual Acuity.

Visual acuity was measured both for near and for distant vision. For distant vision the results were obtained by means of the 'E' test. The chart was well lighted and the subject was seated ten meters from it. This distance answered very well for all the subjects but four. These could not quite make out the positions of all the letters in the last line on the chart at ten meters, but could do so at nine meters. The figures in Table XIII are the ratios of the distance at which the letters were read to the distance at which they should be read according to the chart. Results were also obtained by means of the Snellen test types, but these agree so closely with those of the 'E' test that there was no need of giving them.

Near vision was measured in two ways. The results used in all but two of the correlations were obtained by means of the Galton

TABLE XIII.—VISUAL ACUITY.

'E' test.				Galton Test.			Diamond Type.			
	Both.	Right.	Left.		Right.	Left.		Both.	Right.	Left.
H. W.	2	2	1.5	G. S.	85	85	H. W.	90	72	65
J. M.	2	2	1.5	J. M.	85	72	H. C.	76	71	55
H. C.	1.8	1.5	1.5	W. R.	72	85	S. F.	75	65	66
G. S.	1.8	1.5	1.5	H. C.	85	52	J. M.	75	70	65
G. B.	1.8	1.5	1.5	S. F.	72	72	G. S.	72	57	61
F. H.	1.8	1.5	1.5	F. H.	72	72	E. W.	70	68	68
S. F.	1.5	1.5	1.5	L. W.	72	72	F. H.	70	63	62
E. W.	1.5	1.5	1.5	G. B.	72	72	L. W.	67	63	63
F. B.	1.5	1.5	1.5	H. R.	72	72	W. R.	67	60	62
J. S.	1.5	1.5	1.5	J. S.	72	61	G. B.	61	55	55
P. L.	1.5	1.5	1.5	W. B.	61	61	J. S.	61	50	55
W. R.	1.5	1.5	1.0	P. L.	61	61	F. B.	60	44	57
H. R.	1.5	1.5	1.0				W. B.	58	46	39
L. W.	1.5	1.0	1.0				P. L.	51	49	42
W. B.	1.5	1.0	1.0				H. R.	50	50	50
F. C.	1.0	1.0	1.0				F. C.	45	45	45
A. A.	1.0	1.0	.66				A. A.	40	38	35

eye tester. By means of this apparatus the subject is required to read Arabic numerals while looking with one eye through a small aperture. The numerals are one millimeter in height and are mounted ten in a line on small frames removed from 14 to 100 cm. from the eye. The distance at wihch the subject could read correctly at least eight figures in each of several lines was taken as the measure of his acuity.

The other test consisted in reading the extract printed in diamond type (No. 1), on the standard optician's reading chart. The chart was supported nearly vertically in good light and the subject was requested to read orally at the greatest distance possible for him. The readiness with which he read allowed the operator roughly to judge the distinctness with which the print was seen, which he aimed to have equal for each subject.

In the twelve subjects that took part in both tests there is a displacement of 20 per cent in the two orders. The tests, of course, are not entirely comparable, but the correlation is nevertheless lower than one would expect from the differences in the matter seen. With the Galton test one is fairly sure to get the best record of each subject, but many people will not nove the head back as far as they actually could when the matter is left to them.

All the figures in Table XIV indicate direct correlations between visual acuity and the size of the field of acute vision. The correla-

TABLE XIV.—VISUAL ACUITY CORRELATED WITH:

			No of cases compared.	Percent of displacement.	Pearson coefficient.
Area	—diamond type—	both eyes	15	37	+.40
Horizontal diameter	" "	" "	16	30	
Area	—Galton test	" "	15	31	+.69
Horizontal diameter	" "	" "	15	23	+.69
Area	" "	right eye	10	24	
Horizontal diameter	" "	" "	10	20	+.62
Area	" "	left "	10	26	
Horizontal diameter	" "	left "	10	16	+.74
Area	'E' test	both eyes	16	35	
Horizontal diameter	" "	" "	16	38	+.44
" "	" "	right "	10	35	
" "	" "	left "	10	29	

tions are higher for near than for distant vision. Omitting the test with the diamond type, which is clearly less reliable than the Galton test, the figures for near vision vary from 16 to 31 percent of displacement, and from +.62 to +.74 in the Pearson coefficient. Two comparisons were made in each case, one between acuity and the horizontal diameter of the distinct visual field, and one between acuity and the area of this field. The correlations are in the main higher when the comparison is made with the horizontal diameter instead of the area, and I am inclined to think that the diameter is the better basis of comparison. The objects in our environment are distributed chiefly on the surface of the earth, hence the horizontal range is the one most used. For this reason one would naturally expect it to be more closely related to keenness of vision than to the area as a whole. In some animals, as the horse and the cow, the fovea, as far as one can be made out, consists of a long horizontal band.[1] This makes, in their case at least, the size proportional to the horizontal extension.

The correlations made with the data obtained from the diamond type test are lower than those made with the data from the Galton test. This is very likely owing to the fact that the test is less accurate. If this is the explanation it suggests that if still more perfect measurements were compared than were used here, still higher correlations would be obtained. Defects seldom influence different determina-

[1] James Rollin Slonaker, 'A Comparative Study of the Area of Acute Vision in Vertebrates,' *Journal of Morphology*, Vol. 13, pp. 475–476.

tions in the same direction and so decrease the normal correlations. It was our aim to exclude eyes whose defects would be likely to distort the results, but in this we are not entirely successful.

The correlations between visual acuity for distant vision and the size of the field of acute vision are smaller than those for near vision. The discrepancy is, no doubt, owing to the fact that slight defects in accommodation and refraction make themselves felt more in distant than in near vision. The percent of displacement between near and distant vision is 27, indicating only a medium degree of correlation. Measurements of the same trait are compared here, but the measurements were obtained under different conditions so that factors operative under one were not operative under the other.

The fact that here is a correlation between visual acuity and the size of the acute area would suggest that both may be a function of accommodation and refraction. If this is true it is so to only a slight extent, because a person with a defective mechanism for focusing the light is but little more likely to have a small field than a person without known defects. I had no exact means of ascertaining amount of defect, but from making various measurements on each subject, I learned quite accurately the condition of all the eyes. Arranging them then in the order of their amount of defect, and comparing this order with that of the ascertained fields of acute vision, I obtained a displacement of 38 percent. This leaves a part of the correlations still to be accounted for. This may be done by assuming that both traits are in part functions of the quality of the retina. A fovea that is keen is as a rule also larger than one that is less keen. The quality and the amount of the elements for acute vision go together.

Reading.

One of the primary objects of this investigation was to relate the facts of vision brought to light to the psychology of reading. This field has been cultivated extensively ever since the researches of Cattell[1] on the experimental side and those of Grashey[2] on the pathological side paved the way. In the last decade activity in its cultivation has been renewed by the work of Erdmann and Dodge.[3] But up to the present time the reading process has not, as far as I am aware, been definitely related to the phenomena of vision.

On the side of reading, the reading rate and the number of read-

[1] Various articles in Wundt's *Philosophische Studien*, in *Brain* and in *Mind*. They will be more definitely referred to later.

[2] *Archiv für Psychiatrie*, XVI, p. 654ff.

[3] *Psychologische Untersuchungen über das Lesen auf Experimenteller Grundlage*, Halle, 1898.

ing pauses per line were determined. The reading rate was determined by means of ten different selections. These consisted of three selections from *Robinson Crusoe,* numbers 2, 13, and 22 of Professor Edward L. Thorndike's assortment, averaging 219 words each; three poetical selections consisting of *The Track-Walker* by William H. Woods, the first four stanzas of *Evolution* by Langdon Smith, and lines 39 to 62, Part I, of Longfellow's *Evangeline,* averaging 240 words each; three selections from educational literature consisting of two passages from an educational journal and paragraph 4, chapter 3, of Bagley's *Educative Process,* averaging 249 words each; and the first five and one-half pages, 1280 words, of George Herbert Palmer's lecture, *The Glory of the Imperfect.*[1] In all, these passages contained 3405 words. Different types of material were selected so as to get a more complete measure of each person.

The material is indicated in detail so that it may be used by others in similar experiments. With the exception of the passages from an educational journal, all are available. The selections from *Robinson Crusoe* may be had from Professor Thorndike of Teachers College. *Evolution* is printed in the *Scrap Book* for April, 1906, and *The Track-Walker* appeared in the *Youths' Companion* during the school year of 1899 to 1900. The location of the passages from Longfellow, from Palmer and from Bagley are indicated above.

For experiments in reading, as for experiments in vision, we are in need of standards. It is now quite impossible, except in a rough way, to compare the work of one investigator with that of another. Romanes,[2] Quantz[3] and Huey[4] do not even mention the book or passages they used in determining reading rate.

Only the normal silent reading rate was determined. During the test the subject was comfortably seated in an office chair and he was requested to read silently for the thought as he would when reading by himself. He was told to be ready to repeat the thought in his own words, and this was frequently requested. The subject gave a signal when he was ready, and began reading on the snap of the stop-watch. At the conclusion he gave a signal with the hand by which the operator stopped the watch. Time was recorded in seconds and tenths of seconds.

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[1] Published by T. Y. Crowell & Co., New York and Boston.

[2] G. J. Romanes, *Mental Evolution in Animals,* p. 126.

[3] J. O. Quantz, 'Problems in the Psychology of Reading,' *Psychological Review,* Mon. Sup. Vol. II.

[4] E. B. Huey, 'Psychology and Physiology of Reading,' *American Journal of Psychology,* Vol. 12, p. 295.

It was the intention to have each subject read the passages twice, but circumstances permitted this in only thirteen of the twenty-two cases. The second reading was done in the same manner as the first and the two were from three to ten weeks apart.

The results are given in Table XV. The numbers represent words read per second. The subjects are arranged in the order of their reading rate as determined by the first reading. The slowest reader, P. L., was the Chinese student mentioned before. He has been in this country only two years and has not yet acquired a ready

TABLE XV.—READING RATE.

	Total.	Robinson Crusoe	Poetry.	Education.	Palmer.	Total second reading.
G. S.	8.90	9.5	7.4	10.2	8.8	11.07
V. H.	7.97	8.4	6.7	9.0	8.5	
A.A.	7.72	9.0	7.0	7.1	7.9	
H. C.	7.21	7.7	7.1	7.1	7.7	
G. B.	6.80	6.8	6.0	6.6	7.3	9.15
L. W.	6.63	7.1	5.5	6.2	7.4	7.74
H. R.	6.41	7.3	5.9	5.7	6.7	6.90
B. B.	5.82	7.9	5.7	5.5	5.3	
J. M.	5.15	5.9	5.0	5.6	4.6	5.26
E. W.	5.08	5.7	4.7	4.7	5.3	9.38
R. L.	5.08	5.2	4.5	4.8	5.5	
F. B.	4.95	5.6	4.1	5.2	5.1	5.30
H. W.	4.90	4.9	4.5	5.2	4.5	
S. F.	4.90	5.5	4.3	5.3	4.8	5.73
W. R.	4.85	5.2	4.9	5.4	4.3	5.73
F. C.	4.66	5.5	4.5	4.3	4.5	
E. D.	4.37	4.9	4.8	4.3	3.9	
W. B.	4.36	4.7	4.1	4.2	4.4	5.16
J. H.	4.09	4.6	3.8	4.1	3.9	
J. S.	3.85	4.8	3.2	3.8	3.8	4.31
F. H.	3.29	3.4	3.0	3.4	3.2	3.74
P. L.	2.76	3.3	2.4	3.0	2.6	3.67

control over the language. His record was never included in the comparisons and correlations that follow. Subject J. S. is the one with the small acute field. His record is excluded from the comparisons involving the size of the field.

The usual individual differences are found. The absolute number of words read per second compares well with the numbers given

by Quantz,[1] by Huey,[2] and by Dearborn.[3] The variation in rate is nearly as 3–1. This is just about the variation indicated by the figures of Huey and of Dearborn. Romanes[4] found a variation of 4–1.

The question is sometimes raised whether a person who is a rapid reader in one kind of material is also rapid in a different kind. So far as the material used illustrates different kinds of reading matter, the question is answered in the affirmative. A similar conclusion was reached by Dearborn.[5] Compared with the rank determined by the average for the total, the percentages of displacement vary from 6.6 for 'education' and 11 for 'poetry.' When the passages from 'Robinson Crusoe' are taken as the standard, the displacements are 12 percent, 12.3 percent and 13.8 percent respectively for 'Palmer,' 'education,' and 'poetry.' The Pearson coefficients are .92, .90, and .94. Poetry shows the greatest percent of displacement in each case, indicating the lowest correlation, but its Pearson coefficient indicates a slightly higher correlation with 'Robinson Crusoe' than those of either of the remaining two prose selections indicate. But the differences in each case are too small to deserve more than passing notice.

With the exception of an occasional passage, the second reading was uniformly faster than the first, but otherwise it tallies well with it, except in one case. Considering twelve subjects that read twice, E. W. moved from median in the first reading to second place in the second reading. This seems to have been owing to different physical condition. The subject was fatigued and languid during the first reading, while she was tense and nervous during the second. But even with this record the percent of displacement is only 11; without it, it is 5.5. This shows a high degree of correlation and indicates that the order as determined by the first reading is highly reliable.

It is interesting to compare the gain of the rapid readers with that of the slow. The maxim that to him that hath shall be given seems to hold. The three fastest readers read on the average of 1.9 words more per second in the second reading than in the first, while the three slowest read on the average only .53 of a word more. The respective percents of increase are 26 and 13, showing even the relative gain of the fast readers to have been greater. As it is very proba-

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[1] *Loc. cit.*, p. 12.

[2] *Loc. cit.*, p. 296.

[3] Walter Fenno Dearborn, *The Psychology of Reading*, this series, Vol. 1, No. 4, p. 117.

[4] *Loc. cit.*

[5] *Op. Cit.*, pp. 117–118.

bly harder to improve from 13 percent to 26 percent than from zero to 13 percent, the gain of the rapid readers is more than twice as great.

Before considering the correlations of reading with the phenomena of vision, the subject of reading pauses must be briefly considered. It is now well established that in reading, the eyes do not move with uniform speed across the page, but do so with successive stops and jerks. The first to observe this were Lamare and Javal.[1] They studied the movements by means of a microphone attachment to the upper eyelid. The sounds they magnified were produced by the eye moving against the lid. Since then the subject has been studied by Landolt,[2] Erdmann and Dodge,[3] Huey[4] and Dearborn.[5] Landolt had his subjects read slowly and observed their eyes directly. Erdmann and Dodge observed the reflection of the eyes in a mirror, a method I also used and that will be described later. Huey fastened a light plaster of Paris cup and aluminum pointer (Delabarre Eye-cup) to the reader's eye and by means of it secured a permanent record on the smoked drum of a kymograph.

Dearborn obtained his record by means of the Dodge falling-plate camera. It was by means of this instrument also that I obtained the record of the number of reading pauses per line.[6] The instrument records the reflection of a beam of light from the cornea on a slowly and evenly falling sensitive plate. The head of the reader is firmly supported by means of a head-rest and mouthpiece, so that head movements are eliminated as far as possible. In reading then the only prominent movements come from the eyes, and as they change their position the reflected beam of light suffers corresponding changes which are recorded on the falling plate. A permanent record is thus made of all movements and pauses which may in most cases be readily counted on the developed plate without other aid.

Judd, McAllister and Steele, instead of photographing a beam of light reflected from the cornea, took kinetoscopic pictures directly

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[1] *Annales d'Oculistique*, 1879, Tome LXXXII, p. 252.

[2] *Archives d'Ophtalmologie*, II, 1891, pp. 385–395.

[3] *Psychologische Untersuchungen über das Lesen.*

[4] *American Journal of Psychology*, Vols. IX, XI and XII.

[5] *The Psychology of Reading.* For a review of the literature, which will not be attempted here, the reader is referred to Huey and to Dearborn.

[6] The apparatus was here used substantially as by Dearborn, to the third chapter of whose study the reader is referred for cuts and a full description. The original apparatus is described by the inventor, Professor Raymond Dodge, in the *Psychological Review*, Vol. VIII, pp. 147–151, and in a more recent form in the *American Journal of Physiology*, Vol. VIII, pp. 307–310.

of the eye marked near the pupil with a flake of Chinese white.[1] Against the method here employed they offer a criticism. They maintain that, as the cornea is not flat, it is too imperfect a reflector to make the records reliable. The movements recorded are said not to correspond in amount to those that the eye makes. Professor Dodge on the other hand has comparable records, as yet unpublished, taken by both methods which go to show that the criticism is much exaggerated, if not entirely invalid. At any rate, the criticism, even if true, would not affect my results. The only data I used are the number of pauses per line, the faithful record of which is not questioned.

In addition to getting records with a camera, I got some by means of a mirror, the method used by Erdmann and Dodge.[2] In the application of this method the reader and the experimenter are seated on opposite sides of a narrow table. The reading matter is laid flat upon the table and beside it is placed a mirror. The reader takes a comfortable position, supporting his head with both hands so as to minimize head movements. The operator gets a good reflection of the reader's eyes in the mirror and after some practise can readily observe, count and record all movements. At first the task of catching all the movements seems hopeless, but practise will soon give one confidence in his count. It is easier to observe the movements than the pauses, but when one does this he should remember, when coupling his results, that there is always one more pause per line than there are movements.

In four cases the mirror records duplicate the photographic records, and in two they stand alone.

A glance at Table XVI shows that the results obtained by the two methods are in close agreement, indicating that the mirror method is accurate enough for most purposes when one wants to obtain only the number of pauses per line. The discrepancy is largest in the records of subject H. R. She is quite a rapid reader but makes many eye movements per line, most of which are small and so hard to count.

The passages read in this connection were taken from Palmer's lecture on *The Glory of the Imperfect* and from the educational journal referred to above. They were placed approximately 30 cm. from the eye, the distance used in mapping the field of vision. The same lines were not always read by the different subjects. Skipping about was necessary because, after several trials with the same passage, it became too familiar to give trustworthy results. A comparison of

[1] *Psychological Review*, Monograph Supplement, Vol. VII, No. 1.

[2] *Op. Cit.*, pp. 46–47.

TABLE XVI.

	Camera, Pauses per Line.				Mirror, Pauses per Line.			
	Palmer.	M. V.	Education.	M. V.	Palmer.	M. V.	Education.	M. V.
G. S.	3.62	.67	4.38	.60				
L. W.	3.50	.50	5.83	.83	3.76	.48		
H. C.					3.70	.43	6.00	.52
G. B.	5.70	.61	8.60	.88				
J. M.	6.00	.50	8.50	.50				
S. F.	5.62	.57	9.00	.40	5.80	.59		
J. H.			9.30	.67	5.80	.57		
W. R.	6.40	.66	9.00	1.17				
W. B.	5.75	.67	9.75	.38				
H. R.	7.00	1.11	9.00	.83	5.60	.69		
J. S.	6.25	.56	10.00	.40	6.20	.64		
F. H.	7.40	.50	9.75	1.37				

the records from the same subject showed, however, that the number of pauses per line did not materially vary in different selections from the same article.

The lines in 'Palmer' are 80 mm. long and average 9 words per line, while those in 'education' are 125.5 mm. long and average 14 words per line. In the average number of words read per fixation, the subjects varied from 1.2 to 2.5 in 'Palmer' and from 1.4 to 3.2 in 'education.' The average number of words read per fixation was 1.6 for 'Palmer' and 1.7 for 'education.' The average extent of the visual field covered per fixation varied from 11 mm. in the slowest reader to 31 mm. in the fastest. In all of these subjects the horizontal extent of the field within which they could still distinguish the *n* and the *u* 90 per cent of the time varied from 40 to 71 mm., or from 7.6 to 12.5 degrees. It was 40 mm. in the slowest reader and 43 mm. in the fastest. This indicates that probably not even the most rapid reader ever made use of the entire extent of his visual field available for seeing words. There is consequently no time lost in reading, owing to the way the words are arranged on the page. With print of ordinary size, we can take in the material faster than the mind is able to assimilate it, and there is no call for methods of arranging the words so that more can be crowded simultaneously into the field of distinct vision.[1]

[1] Cf. Cattell, *Phil. Stud.*, Vol. III, p. 125.

The correlations with reading rate are given in Table XVII. The only pronounced correlation is found inversely with the number of reading pauses. The rapid readers make quite uniformly fewer

TABLE XVII.—CORRELATIONS WITH READING RATE, ETC.

	No. of cases compared.	Percent of displacement.	Pearson coefficient.
Reading rate and horizontal distinct vision	16	56	—.06
" " " visual acuity	16	35	
" " " reading pauses	12	16	+.81
" " " 'A' test	16	33	
" " " 'A' test (corrected)	16	40	+.36
" " " lines seen	10	73	
" " " association	11	51	
Horizontal distinct vision and reading pauses (inverse)	10	42	—.10
" " " " 'A' test	16	43	
" " " " 'A' test (corrected)	16	50	
" " " " lines seen	9	33	+.13

pauses than the slow readers. The correlation is so high that a vital connection between the two phenomena cannot be doubted. In twelve cases the percentage of displacement is 16 and the Pearson coefficient +.81.

Dearborn did not work out any coefficients of correlation between reading rate and reading pauses and his data are not so given that it is possible for us to do so, but he reaches substantially the same conclusion as I do.[1] He says (p. 122): "A wider 'spanning' of attention—as denoted both by the greater frequency of long pauses at the beginning of the line and by fewer fixations per line—is characteristic of the more rapid readers. The slow readers have a narrower span, or working extent of attention, and a greater total arc of movement."

The Pearson coefficient of correlation between the horizontal extent of acute vision and reading rate is —.06 and the percent of displacement 56. Correlated inversely with the number of reading pauses the corresponding figures are —.10 and 42 percent. The fact that there is no correlation between these phenomena came somewhat as a surprise. One would think that a larger area would enable a person to see distinctly a larger portion of a line and so allow him to make fewer fixations and read more rapidly. But such is

[1] *Op. Cit.*, Chapter XIII.

evidently not the case. Visual perception seems to be in a large measure independent of the quality of the eyes. The percent of displacement between reading rate and visual acuity is 35. Arranging the eyes again in their order of freedom from defect, the percentage of displacement with reading rate is 45.

The coefficients of correlation of other tests of visual perception show a similar independence of the quality of the eyes, as well as a lack of correlation among themselves.

The "A" test consists of marking as rapidly as possible one hundred A's distributed by chance among four hundred other capital letters. The time is taken with a stop-watch. It is supposed that the test measures rate of perception. Most of the subjects marked the sheet four different times, but with five circumstances permitted it to be done only once.

The results, which are summarized in Table XVIII, are given in two columns. In the first column is given the average time in sec-

TABLE XVIII.—'A' TEST.

L. W.	.65	.40	S. F.	.83	.61
G. S.	.75	.43	F. H.	.87	.54
H. R.	.79	.51	G. B.	.92	.59
A. A.	.80	.53	H. C.	.92	.55
W. R.	.80	.54	J. S.	.93	.59
J. M.	.81	.56	P. L.	.93	.60
F. C.	.82	.50	E. W.	.97	.58
H. W.	.83	.51	F. B.	1.11	.81

onds the subject took to see and mark one A, while in the second column is given the time with the marking or motor time subtracted. In connection with the A test each subject marked as rapidly as possible one hundred dots in a similar manner as he marked the A's, the time thus consumed was taken to be the subject's motor time, and was subtracted from the results as given in the first column. Both results are given because it is not clear that this time should be subtracted. The time it takes to mark the A's is not all lost from perception; in fact, only a small fraction of it can be regarded as lost. A person does not not look at the A till he has marked it. As soon as the letter is recognized, the eye passes on to look for another while the hand in a semi-automatic way marks it. Furthermore, the eye seldom, if ever, has to wait for the hand to catch up. It is kept continuously busy looking for letters.

The correlation between the horizontal extent of acute vision and the A test is 42 percent of displacement when the motor time is

not subtracted, and 50 percent when it is. This indicates very little correlation, if any. One might again have supposed that a larger area would be of assistance in finding the letters, but it apparently is not.

When the rank in reading rate is compared with that in the A test, the displacement is 33 per cent; or, when the motor time is subtracted, 40 per cent. The Pearson coefficient in the second instance is +.36. This indicates some correlation but not a great amount. Quantz[1] found a higher correlation between reading rate and perceptive power. He represents the correlation diagrammatically and does not give a numeral coefficient, but the meager data he supplies give a Pearson coefficient of +.88.

The discrepancy between his conclusion and mine no doubt results from the different measures of perception used. Perception is too complex a process to be adequately measured by the A test. Quantz measured it by means of geometrical figures, colors, isolated words, and sentences. These were exposed for a short time (½″ and 1″), and "the subject was required to name aloud, in order, and as rapidly as possible..........as many as he was able to see while the card was exposed" (p. 2). The card was shown until everything on it was read, the subject beginning to read at each exposure where he had ended in the preceding. It is at once apparent that these tests were far more analogous to the reading process than the A test. In fact, the tests with the words and the sentences were essentially reading, and the forms and colors were perceived much as words are perceived in reading. Instead of saying that these tests show a correlation between visual perception and reading, one is tempted to say that they show little more than a correlation between tachistoscopic and ordinary reading.

Quantz draws the conclusion also that these tests show that the reading process depends largely on physiological influences because he assumes that perception is largely a physiological function (p. 50). This is far from clear, for such a conclusion can no more be drawn from the tests used than from the reading process directly.

Another test that was made and correlated with the horizontal extent of acute vision and with reading rate was the number of small vertical lines that could be seen simultaneously during an exposure time of 50 sigma. The lines consisted of the capital letter I printed on cards with a Fay-Sholes typewriter. They were approximately 2.5 mm. apart.

A similar test was made by Cattell for the purpose of measuring

[1] *Psych. Review*, Monograph Supplement, No. V, pp. 16–17.

the grasp of consciousness.[1] As lines he used also the capital letter I printed with a typewriter. These lines he arranged from four to fifteen per card on twelve cards, and exposed them in chance order by means of the fall-chronometer. Results were obtained from eight subjects. A series consisted of sixty exposures, or five for each card, except that with two subjects twenty-five exposures of each card were made. The number of lines seen correctly every time varied with the different subjects from three to six, remaining, however, constant for each. Practise seemed to have no influence on the precision of the judgments.

From 3 to 11 lines per card were used in my experiments, and each was exposed ten times for seven subjects and fifteen times for three, except for J. S., whose case will be considered separately. The exposures were made with the fall-chronometer. A glance at Table XIX shows that from 4 to 7 lines were always judged correctly. This is one more than was seen by Cattell's subjects. The difference may be owing to the longer exposure time used or to a difference in the subjects. The exact limit for each subject is not readily established. F. H., for example, made but one error on eight lines and two on nine. He has had much practise with tachistoscopic experiments, which may in part account for his large span in this respect. The precision of the judgments did not improve with practise, except for one subject, G. S. In the first five series the limit of the number of lines he always saw correctly was four, and in the second five series it was six. He was conscious of this improvement, having learned to see the lines in groups.

The last two sections of records in Table XIX come from J. S., the person with the constricted acute field. The first one of these records was made in the same manner as those of the other subjects, while in the second the lines were 5 mm. apart instead of 2.5 mm. As is seen from the table, when the lines were 2.5 mm. apart he always saw seven correctly, but beyond eight they looked alike to him. Seven lines occupied a space 15 mm. long, which is the extent of the field within which he could distinguish the *n* and the *u* 75 percent of the time. Outside of this limit the lines looked faint to him, he said. When the lines were 5 mm. apart, he always saw four correctly, while beyond that number they looked alike to him. Four lines again occupied a space of 15 mm., the horizontal extent of his field of vision for the distance used. This corroborates the restricted nature of his field.

The objection might be offered that it is harder to see the lines

[1] *Phil. Stud.*, Vol. III, pp. 123-125.

TABLE XIX.—LINES SEEN.

	W. R.			S. F.			G. B.			F. H.		
3	15–0	3		15–0	3		15–0	3		10–0	3	
4	15–0	4		15–0	4		15–0	4		10–0	4	
5	15–0	5		15–0	5		13–2	5.1	.1	10–0	5	
6	15–0	6		9–6	6	.4	14–1	5.9	.1	10–0	6	
7	11–4	7.1	.3	10–5	6.3	.3	7–8	6.8	.5	10–0	7	
8	13–2	8.0	.1	9–6	7.9	.4	6–9	8.8	.9	9–1	7.9	.1
9	7–8	9.6	.6	11–4	9.0	.3	3–12	8.9	1.3	8–2	8.8	.2
10	7–8	10.1	.5	9–6	9.8	.4	7–8	10.2	.7	5–5	9.6	.6
11	10–5	10.6	.4	9–6	10.6	.8	5–10	10.8	.9	4–6	10.4	.6

	J. M.			H. R.			W. B.			L. W.		
3	10–0	3		10–0	3		10–0	3		10–0	3	
4	10–0	4		10–0	4		10–0	4		10–0	4	
5	10–0	5		10–0	5		8–2	4.9	.1	8–2	5	.2
6	7–3	6.1	.3	2–8	5.2	.8	5–5	5.5	.5	4–6	5.4	.6
7	7–3	6.9	.3	1–9	6.3	.9	4–6	6.2	.8	2–8	6.2	.8
8	4–6	7.4	.6	0–10	7.1	1.5	3–7	7.3	1.1	0–10	6.9	1.1
9	5–5	8.4	.6	2–8	8.4	1.2	1–9	7.6	1.4	0–10	7.9	1.1
10	3–7	9.2	.8	3–7	8.9	1.5	2–8	8.8	1.2	7–3	9.4	.6
11	4–6	10.4	.8	4–6	9.8	1.2	2–8	9.2	2.0	0–10	9.8	1.1

	G. S.			J. S.			J. S.		
3	10–0	3		10–0	3		5–0	3	
4	10–0	4		10–0	4		5–0	4	
5	6–4	4.6	.4	10–0	5		3–2	5.6	.6
6	7–3	5.7	.3	10–0	6		2–3	6.4	1.0
7	6–4	6.6	.4	10–0	7		1–4	6.4	1.0
8	7–3	7.7	.3	6–4	8.5	.5	0–5	6.6	1.4
9	3–7	8.3	.7	2–8	9.9	.9	0–5	5.2	3.8
10	6–4	9.8	.4	5–5	9.9	.5	0–5	5.6	4.2
11	4–6	10.6	.6	7–3	9.9	.1			

when 5 mm. apart than when 2.5 mm. apart, and that for this reason he could see only four in the second test. This objection does not hold. Two subjects with normal fields found the lines easier to see when 5 mm. apart than when 2.5 mm. apart. H. R., whose limit was five lines when they were close together, never missed six when they were 5 mm. apart, and the writer, whose limit as given in the table is six lines, never missed ten lines in the second test. Ten series were exposed and the number of lines per card varied from three to thirteen. When the lines were farther apart they seemed less crowded and so their number was easier to judge.

In Table XIX the first column for each subject gives the number of times the lines were judged correctly and the number of times they were judged wrongly. The second column gives the average of the number of lines judged to be on a card, and the third column gives the average error.

Two correlations were made, one with the horizontal extent of distinct vision and one with reading rate. With the former the percent of displacement is 33 and the Pearson coefficient +.13. This indicates some correlation, but apparently it makes little difference in seeing a number of lines if one has a large or a small field of distinct vision. The matter seems, in the main, to be one of perception or mental grasp and is central. Between reading rate and the number of lines seen there appears to be an antagonism. The percent of displacement, as figured here, is 73. I took the number of lines seen correctly at least nine times out of ten as a person's measure. If the number of lines always seen correctly is taken as a person's measure, the displacement with reading rate becomes 84 percent.

When it became evident that there would be no significant correlations with reading rate and the various phenomena of vision, a test in controlled association time was arranged, the results of which were compared with reading. The test consisted of five lists of twenty words each, one of which called for opposites, one for synonyms, one for genus or higher class, one for profession or calling, and one for geographical location. In doing the test the subject uncovered one word at a time, giving the item called for before uncovering the next word. The operator took the time with a stop-watch that was necessary to complete each list.

The order the subjects obtained from the average of all the lists was compared with the order for reading rate. The correlation, 51 percent of displacement, is as close to no correlation as one could expect. Clearly reading is not analogous to controlled association; and if reading rate indicates one kind of mental quickness, controlled association time indicates another kind that is unrelated to it. Psychologically the two processes are, of course, quite different. In reading the symbol seen, as a rule, does nothing more than reinstate in a general and schematic way the meaning that has become connected with it, while in controlled association a very specific meaning has to be aroused and then a suitable symbol standing for this meaning has to be selected and enunciated or written.

The results of the five types of controlled association used do not correlate highly among themselves. The smallest percent of displacement is between the 'genus' and the 'profession' tests, which is

22 per cent. When the results of the 'synonym,' 'genus,' 'profession,' and 'geographical' tests are compared with the results of the 'opposites' test, the percents of displacement are respectively 29, 33, 40, and 38. The percents of displacement with reading rate of the results of the 'opposites' test is 56; 'synonym,' 56; 'genus,' 45; 'profession,' 45; 'geographical,' 45.

The above comparisons make it evident that there is litle or no correlation between reading rate and the physiological phenomena of vision. This is true at least in eyes that are not abnormally defective. A person that is nearly blind would, of course, have his reading interfered with, but the variations that exist in the eyes of the large majority of readers are approximately without influence on the reading process. If this conclusion is correct, the essential factors that determine reading must be looked upon as central rather than peripheral. It is not a matter of getting the material to the brain, but of assimilating it after it gets there. There is, however, one fact that is at variance with this conclusion. This is the correlation between the number of reading pauses and reading rate. A smaller number of fixations per line means that more is seen per fixation, for during the movement of the eye from one fixation to another nothing is seen.[1] Apparently, at least, the amount so seen is a function of the eye. But this may just as well be a function of assimilation. One person can take it more at a glance than another because he assimilates faster. That is, one person makes fewer reading pauses than another because he is a more rapid reader, rather than vice versa. This assumption is in harmony with the facts brought to light by this study, and also with the data obtained by Dearborn. Dearborn found, for example, that "there is a tendency for the slow reader to make both more pauses and longer pauses" (p. 130).

Reading is a process of gaining meaning from symbols. Meaning applies originally to objects and relations, and is represented in the mind by a much abbreviated and condensed form of the experience one has had with these objects and relations. By experience is meant more than the data given by the senses and the kinesthetic sensations. It includes emotional, or affective, elements as well.[2] These may in part have been aroused by the sense data directly and they may in part have become merely associated with them. The meaning of 'steamboat' is represented in my mind by more than

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[1] Regarding visual perception during eye movements, see Dodge, *Psych. Rev.*, Vol. VIII, p. 454–465, and Dearborn, *Op. Cit.*, Chap. 5.

[2] Cf. Bagley, 'The Apperception of the Spoken Sentence', *American Journal of Psychology*, Vol. 12, pp. 125–130.

fleeting visual and other sensory and kinesthetic images. Vaguely remembered feelings of joy, anger, fatigue, and certain moods also form a part of this meaning.

These meanings, once they are in the mind, may then become associated with, or attached, to objects and relations that have not been distinctly experienced. I know, for example, that volcanoes are, although I have never seen any. I have, of course, seen pictures of some, but my experience with these pictures does not exhaust my knowledge, or 'meaning' of them. Experience gained from other sources (fire, smoke, etc.) have through reading and otherwise become recombined in my mind and now comprise the meaning of volcano.

Through the power of language and the mental functions that language implies, man singles out particular meanings from his experience and labels them with symbols. In his mental life and in his communication with his fellows, these symbols become the carriers of meaning. They are enabled to be these carriers by having the experiences that comprise the meaning connected with them. Without reinstating in some degree these experiences the symbol would be meaningless. The same symbol, of course, becomes associated with the same or a similar object, and consequently with similar experiences, in different minds. The word 'steamboat' brings in its train certain usually vague but characteristic mental attributes, which are in a measure common to different people. The word, therefore, has a common meaning to these people.

In reading, a similar reinstatement of experience takes place as in thought or in oral communication. The printed symbol arouses the meaning that has through education and experience become connected with it. It is in the rapidity with which this meaning is aroused that we have to look for the cause of the differences in reading rate. This is the conclusion we are forced to after having eliminated the physiological qualities pertaining to the mechanism of vision. We saw that neither visual acuity, retinal sensitivity nor the horizontal extent of acute vision had any significant correlation with reading rate, and that slow readers make both more and longer reading pauses than rapid readers.

But there is still one other physiological factor that has been advanced as influencing reading rate. This is what Dearborn calls the 'motor habit' in reading. In his own words, "A motor habit is evidenced by a rythmical series of the same number of pauses per line, and by a uniform method of time distribution. The latter consists of a comparatively long initial pause followed by two or more shorter

ones of decreasing duration. These may be followed by a somewhat longer pause near the end of the line" (p. 128). He continues in the same paragraph: "These motor habits are most easily acquired in the shorter lines and aid materially in the rapidity of reading. They are, furthermore, one of the characteristics of rapid readers."

The experiments and data upon which he bases this conclusion are indicated in Chapters XII and XIII of his study. The experiments indicated in Chapter XII were done with two subjects, one a rapid and one a slightly slower reader, and were to determine the influence of the length of line on the number, length and distribution of the reading pauses. The same passages were read both in short and in long line arrangements. The rapid reader distributed his pauses more nearly as ascribed above than the slower reader, and both did so more nearly in the short than in the long line arrangements.

In Chapter XIII some data on the rapidity of reading are presented. In one phase of the experiment a subject read a passage first at his normal rate and then at his maximum rate consistent with getting the sense. "There is a decrease in the average duration of the pauses in the second reading, *but this decrease is not made equally in all parts of the line. It occurs chiefly in the last half of the line, and in fact not only is the time of the first fixations not decreased on the second reading, but there is a slight increase in both the average and the total time spent in the initial fixations.*"[1] So far as the text indicates, this conclusion is based on the records of but one subject.

The number of subjects experimented upon and the amount of data compared are clearly not large enough to give one much faith in the validity of the conclusion. What was true of these subjects might not be true of others.

Furthermore, even if the conclusion be correct, cause and effect may here be just the reverse of what they are indicated to be. The 'motor habits' may be a function of the ease and rapidity of reading rather than the reverse. The fact that it is subjectively easier to read short lines than long ones, and to read a passage the second time, may be the cause of the greater regularity in eye movement. What is needed here are experiments with children whose reading habits are still flexible. It is only by elaborate experiments with them that we can determine to what extent, if at all, the reading rate can be increased by the establishment of regular motor habits, and to what extent the two phenomena are merely reciprocal.

By granting that by proper line arrangement in school readers, connected with proper teaching, we can produce more rapid readers through the establishment of right motor habits, it is not claimed

[1] *Op. cit.*, p. 120. The italics are Dearborn's.

that this is the sole, or even a large factor in determining reading rate. "The cause of the slowness of reading may doubtless for the most part be central, and quite apart from this peculiarity."[1]

But the fact that right motor habits cannot greatly increase reading rate does not detract from their pedagogical value. They may still be the chief avenue of increasing reading speed. They are not the sole avenue because mere practise in reading is another. Quantz found a high correlation between extent of reading and reading rate, but here the casual influence can probably not even in the main be attributed to extent of reading. A person who finds reading easy will for that reason read more than one who finds it slow and irksome. Still, all influence cannot be denied to practise.

Dearborn rightly inveighs against a 'habit of slow methodical plodding' in reading that 'varies little whatever the sort and importance of the reading.'[2] He attributes this habit in part to classical study. The classical student pours over his Latin and Greek word by word, and unless this method is counterbalanced in his general reading, he will in time read everything slowly. Another source of this habit of plodding is found in much of the material in our school readers. This is often too difficult and requires the pupil to 'dig' as if he were studying Latin. Our pupils should read easier material and more of it. This would admit of the speed tests Dearborn suggests, which should no doubt have a conspicuous place in the school-room.

There remains open to the teacher, then, three avenues in the teaching of reading that lead to the acquisition of speed, remembering always that one should not expect too much from them. These are (1) material easy enough so that the pupil is not overwhelmed with difficulties, (2) lines not more than 75–85 mm. in length and uniform for each selection,[3] and (3) speed tests. The value of these factors needs still to be investigated.

Reading rate may then be taken to depend chiefly upon the rapidity with which meaning is aroused in the mind after the symbol is seen. This in turn is probably in the main dependent upon a person's native brain inertia.

Some of the factors, however, that comprise the meaning and that bear a relation to reading rate have been ascertained. Since Galton's classic experiments on mental imagery, it has become an established fact that people differ in the imagery most prominent in

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[1] Dearborn, *Op. Cit.*, p. 121.
[2] *Op. Cit.*, p. 121.
[3] Dearborn, *Op. Cit.*, p. 115.

their mental life.[1] The images furnished by the data from the different senses, including the kinesthetic and the muscular sensations, are not equally prominent in the mental life of all. While in most people they are about equally represented, and none are entirely absent in any, still some people are predominantly eye-minded, ear-minded, or motor-minded. Quantz[2] determined these three sensory types and correlated them with reading rate. He found that "the visual type of readers are slightly more rapid readers than the auditory type (p. 49) and that "lip-movement is a serious hindrance to speed of reading" (p. 50). Prominence of lip-movement was taken as a rough index of the motor type. It cannot be taken to stand for it directly because it is not imagery, but the expression of imagery. The prevalence of motor imagery need not necessarily be proportional to it. The conclusion may be taken to be established, however, that when meaning is represented by visual imagery it is more quickly aroused in reading, or permits more rapid succession, than when it is represented by auditory or motor imagery. This need not necessarily mean that visual imagery is inherently more rapid than auditory or than motor imagery. It may merely have the advantage in the reading process because it too is visual. It may well be that in gaining knowledge through the ear the auditory type is more rapid.

Cattell[3] has made the observation that the rapidity of reading and of speaking coincide with each other and perhaps also with the usual rapidity of thinking. If my conclusion, that the rate of reading is almost entirely determined by the rapidity of the central processes, is correct, it is in line with this suggestion. In reading we think the thoughts of the book, for thought is but a succession of meanings, and our rate of reading is determined by the rate at which we can think these thoughts. When we think by ourselves, and think at all in detail, introspection indicates that our thoughts follow only about as rapidly as we read and as we speak.

This would make reading rate an index of a person's rapidity of thought, which is one of the elements of its efficiency. Other things being equal, a rapid thinker can accomplish more than a slow one. But this is not saying that reading rate is an index of the quality or depth of a man's thinking. Romanes, who found a variation of 4–1 in reading rate, thought this had no connection with intellectual per-

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[1] Francis Galton, *Inquiry into Human Faculty*, p. 84f. See also Jastrow, 'Eye-mindedness and Ear-mindedness,' *Popular Science Monthly*, Vol. XXXIII, p. 597f.

[2] *Op. Cit.*, p. 18f.

[3] *Phil. Stud.*, Vol. II, p. 649.

formance. Eminent men of letters and science that he tested were just as likely to be slow as rapid readers. Quantz found some correlation between reading rate and college records, which, however, he recognizes as not a true test of intellectual strength. I had no adequate way of grading or ranking my subjects, nevertheless some positive correlation between mental efficiency and reading rate seems evident, but the amount is small.

SUMMARY AND CONCLUSIONS.

1. The field of distinct vision has no clear cut boundary line, but shades off gradually into indistinct vision.

2. The extent of the field varies with the size, legibility and distance from the eye of the test-units.

3. It appears that between four and five degrees from the center of the fovea there is a zone with slightly less acuity than the adjacent regions. This zone probably corresponds to the slope of the foveal depression.

4. Distributed irregularly over the retina are found imperfections that in some cases amount to blind spots.

5. The shape of the field bounded by points of equal distinctness varies in different individuals from a 'square-oval,' about twice as long horizontally as wide vertically, to a circle.

6. The size of the field varies approximately as 2–1 in the horizontal diameter, as 1.5–1 in the vertical diameter, and as 2–1 in area.

7. Data obtained from members of the Mongolian race indicate no conspicuous variation from the Caucasian race.

8. The shape or oblongness of the field of distinct vision correlates but little, if any, with a person's illusion of the square, or with a person's 'golden section.'

9. The various dimensions of the distinct field apparently do not correlate with the corresponding dimensions of the color zones.

10. Between the size of the distinct field and visual acuity there is a positive correlation, which is higher foı near than for far vision. For near vision the percent of displacement is approximately 22 and the Pearson coefficient +.70. For distinct vision the corresponding figures are approximately 35 percent and +.45. There is also a small amount of positive correlation between the size of the field and retinal sensitivity.

11. There is little or no correlation between the horizontal extent of distinct vision and the 'A' test, the number of lines that can be seen simultaneously, reading rate, and the number of pauses per line. Even a rapid reader does not use all his retinal extent available for seeing words.

12. Reading rate apparently does not correlate with any of the attributes of vision, but it correlates highly with the smallness of the number of reading pauses per line, having a percent of displacement of 13 and a Pearson coefficient of +.81.

13. The data as a whole point to the conclusion that reading rate is in the main determined centrally, by the rapidity with which meaning is aroused after the words are seen.


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